Subtask 3.1D

The Analysis of Heterogeneous Distributions of Fuel, EGR Gas and Temperature in Mixture for Extending Knock Limit of a PCCI Engine

Kazuie Nishiwaki
Ritsumeikan University
and
Takafumi Kojima
Takamatsu National College of Technology

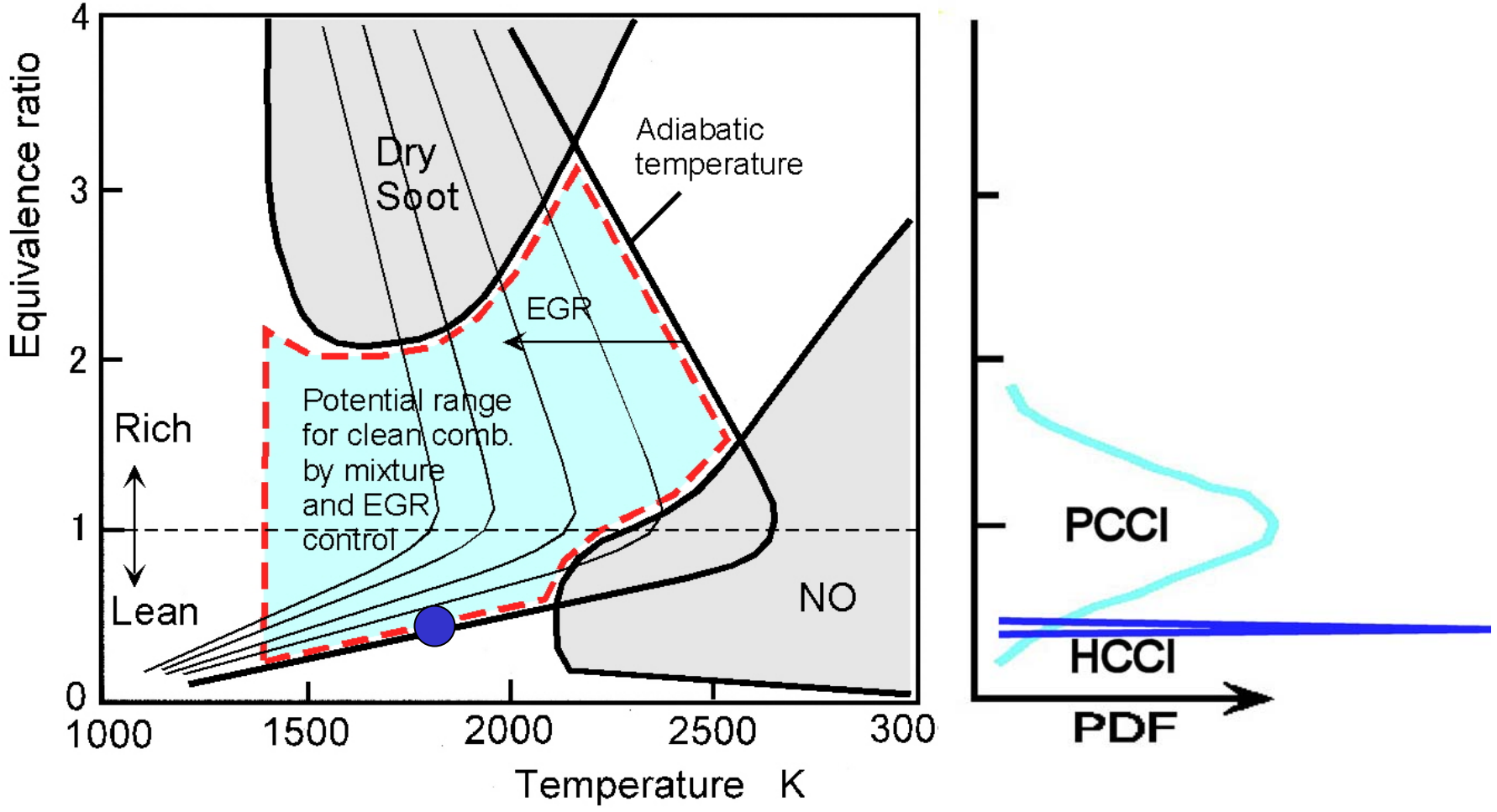
Purpose of the study

- **To summarize the PCCI combustion research conducted in past several years using LES for the systematic analysis of a heterogeneous mixture for reducing abrupt heat release so as to extend a knock limit**

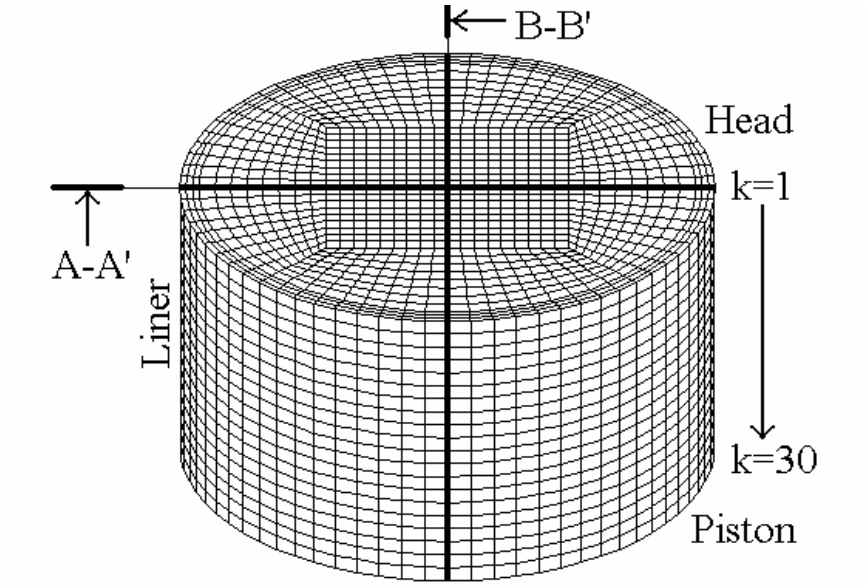
  Mixture heterogeneity includes:

  - **Fuel distribution**
  - **Temperature distribution**
  - **EGR gas distribution**

Background - conditions for clean combustion



Outline of the Model



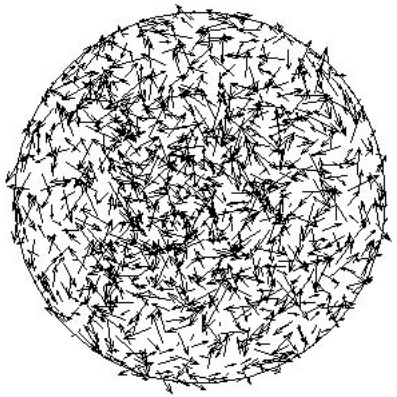
***D*= 82.6mm, *S*=114.3 mm**
600 rpm, C.R.=10
The number of cells=43,200
[cell volume]$^{1/3}$=2.5mm – 1.2mm
(bdc) (tdc)
Measured integral length scale in literature: 4-5mm – 2.5mm
(bdc) (tdc)

- Transport equations for mass, momentum, enthalpy and species mass fractions in spatially filtered forms (LES)
- Sub-grid kinematic viscosity: Smagorinsky model
- Wall boundary conditions: Law of the wall
- Reaction kinetics: Schreiber model – five step global reactions

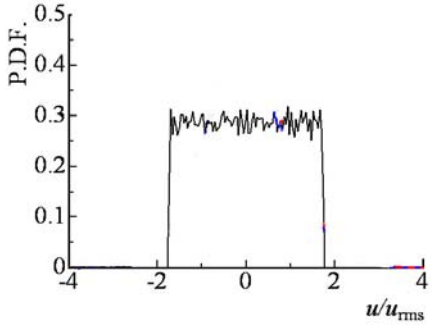
Method for Generating Initial Velocity Field in LES

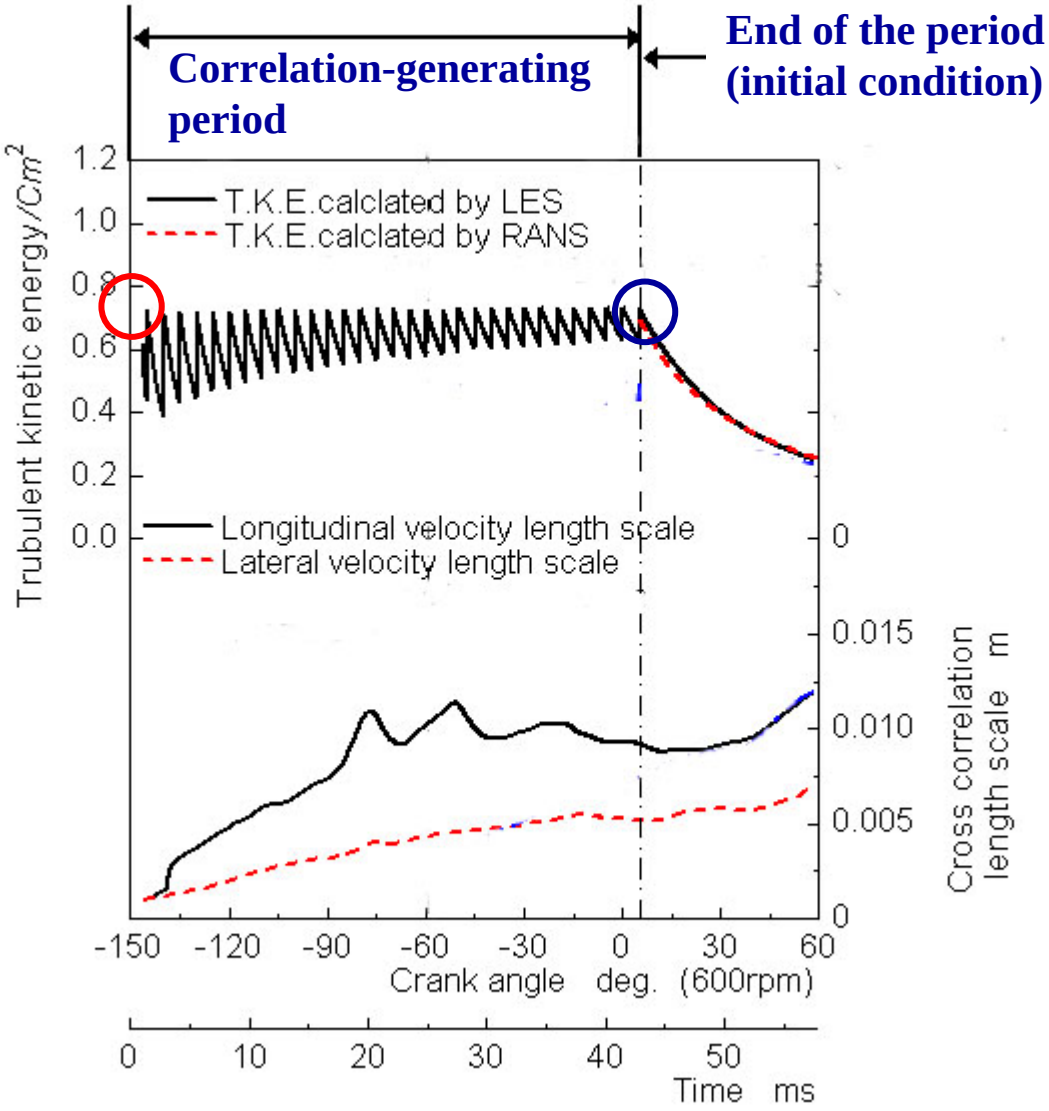
Constant volume process

Uniform random number velocity field

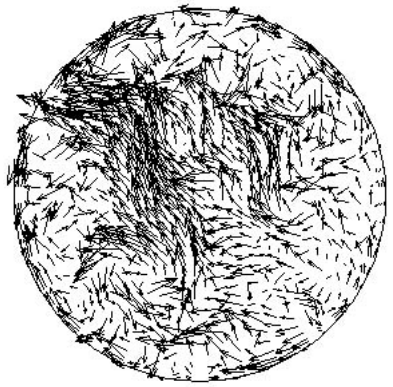


middle(k=12)

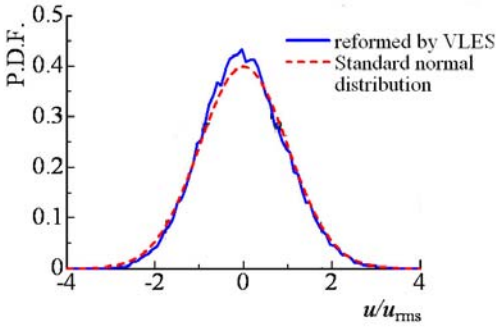




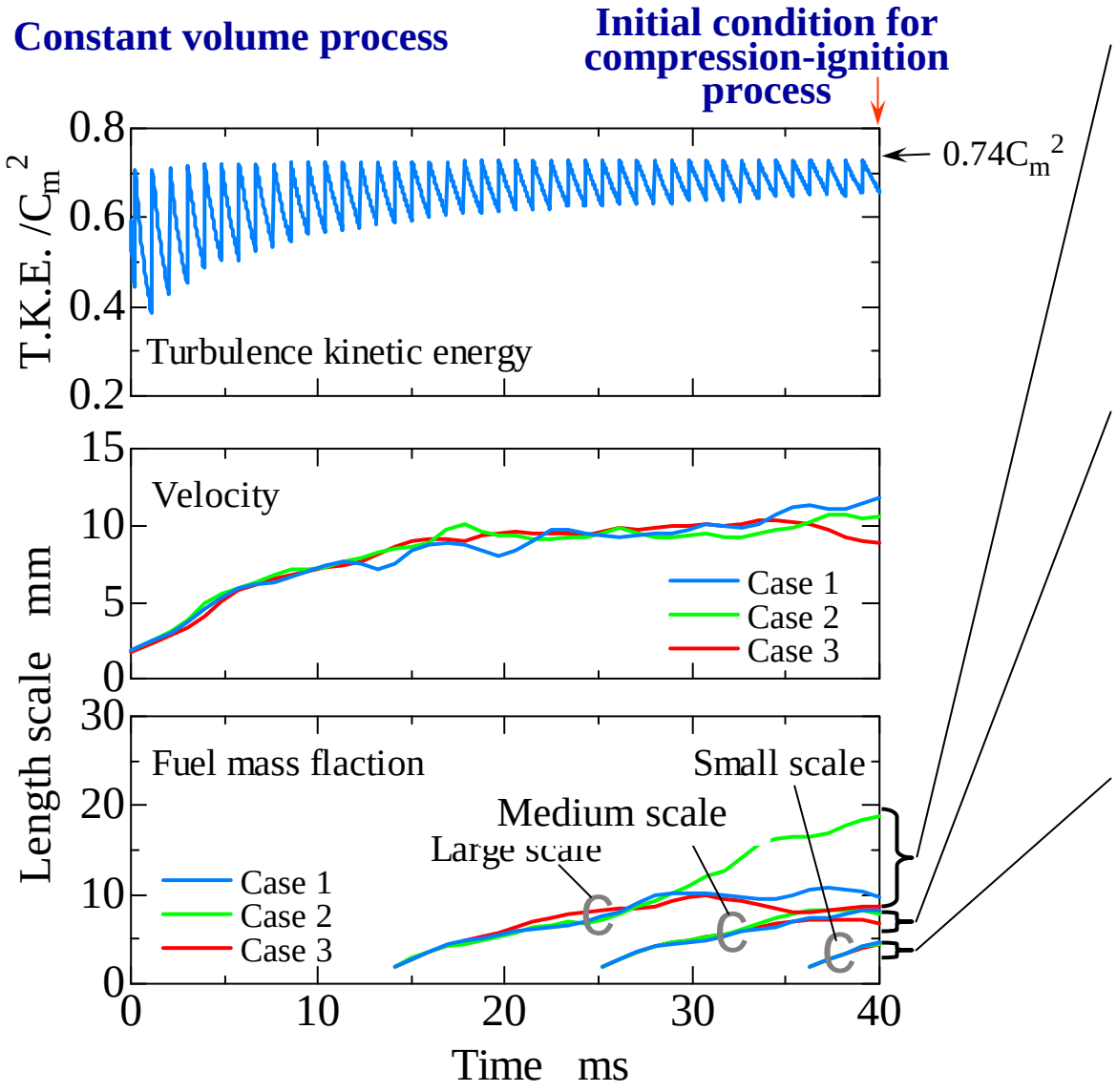
Correlated velocity field

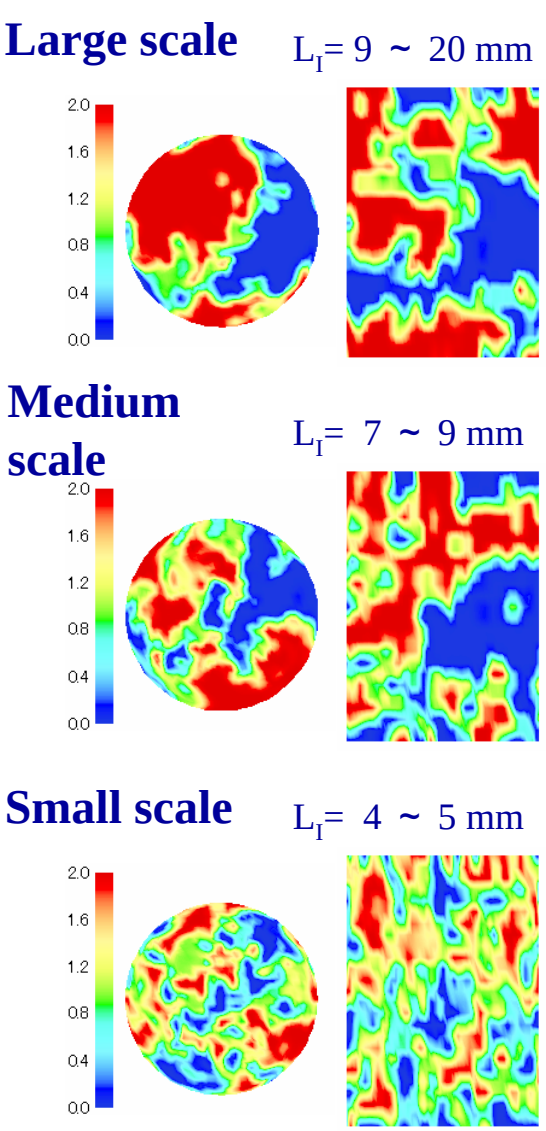


middle(k=12)

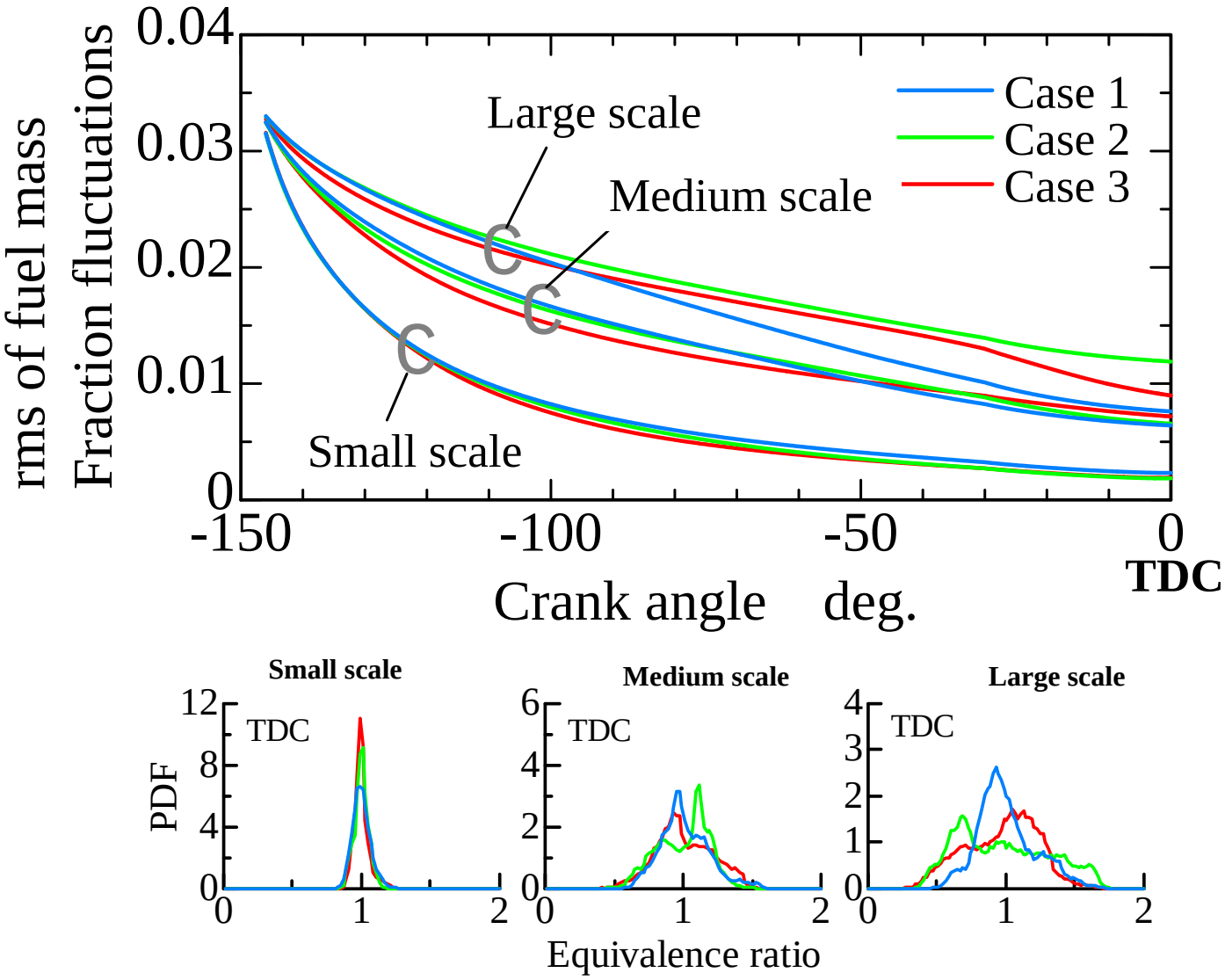


Heterogeneous Field of Fuel Mass Fraction

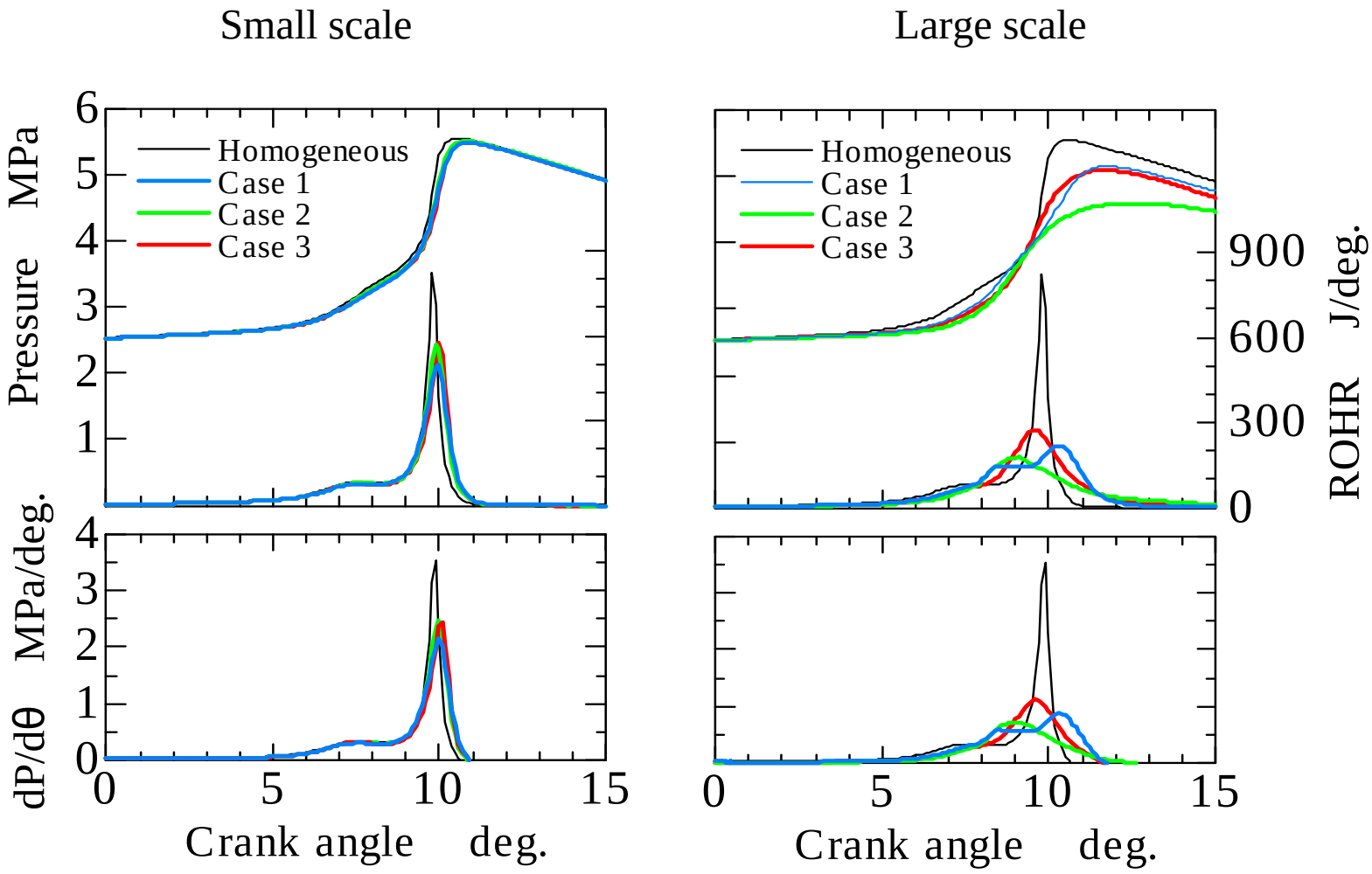




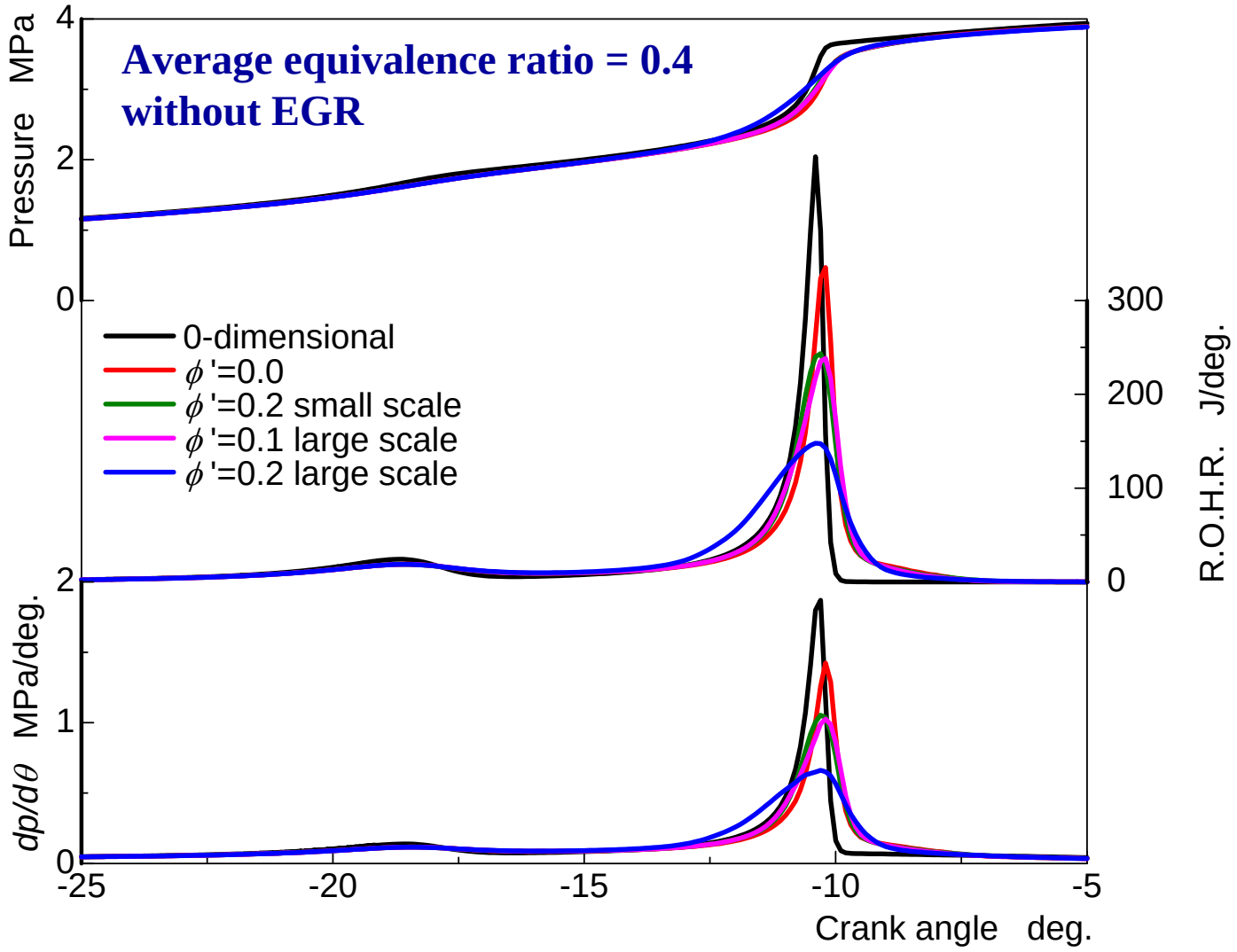
Average ϕ = 1.0; Homogeneous EGR ratio = 0.4



Decay of fuel mass fraction fluctuation during compression; average ϕ = 1.0; homogeneous EGR ratio = 0.4



Cylinder pressures, total heat release rates and *dp/dθ* calculated for large and small initial length scales of fuel distribution;
homogeneous EGR ratio = 0.4, uniform initial temperature = 370 K

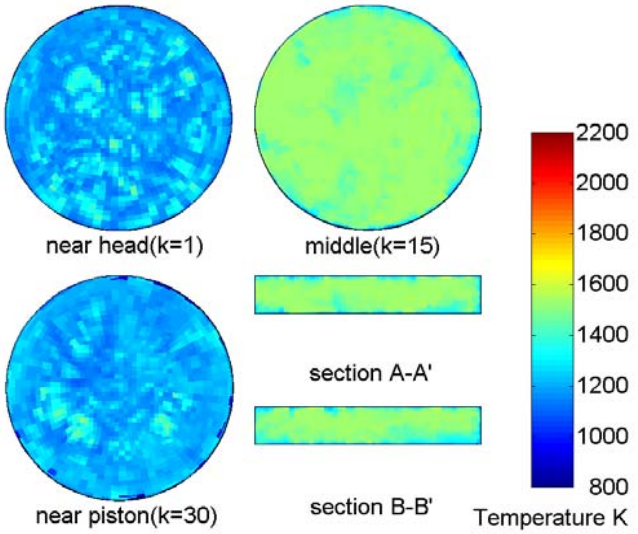


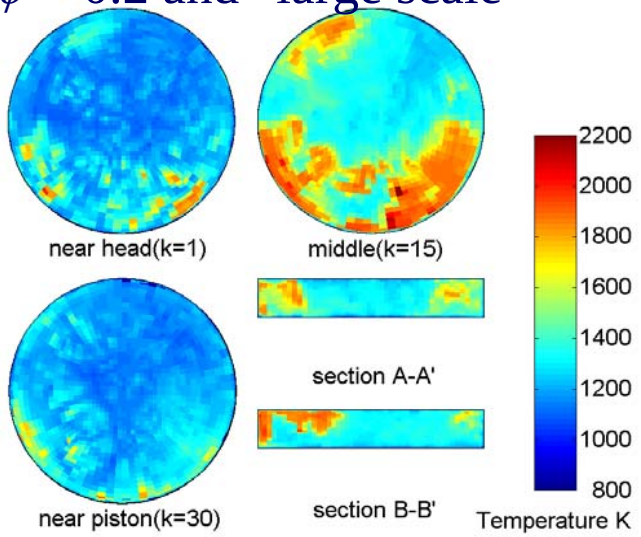
Time histories of cylinder average pressures, total heat release rates and $dp/d\theta$ calculated for four different initial conditions of equivalence ratio fluctuations and the result of zero dimensional calculation; average equivalence ratio = 0.4 without EGR

homogeneous charge

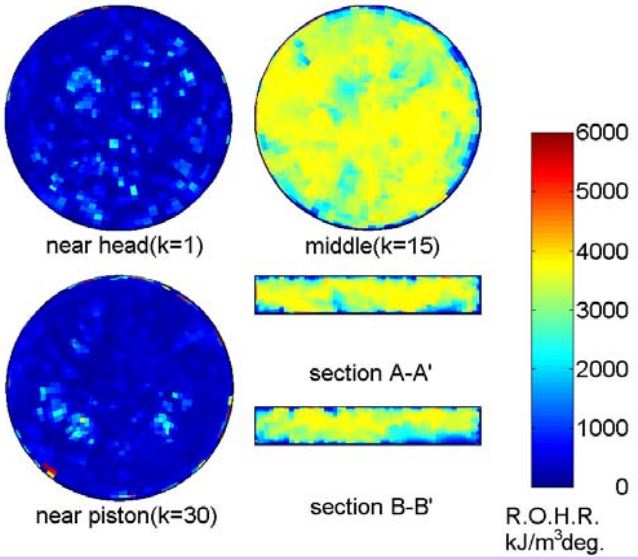
heterogeneous charge;
ϕ'= 0.2 and "large scale"

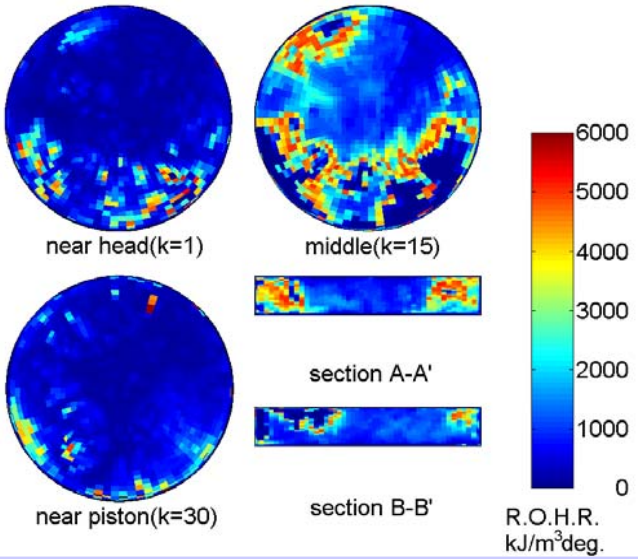
temperature





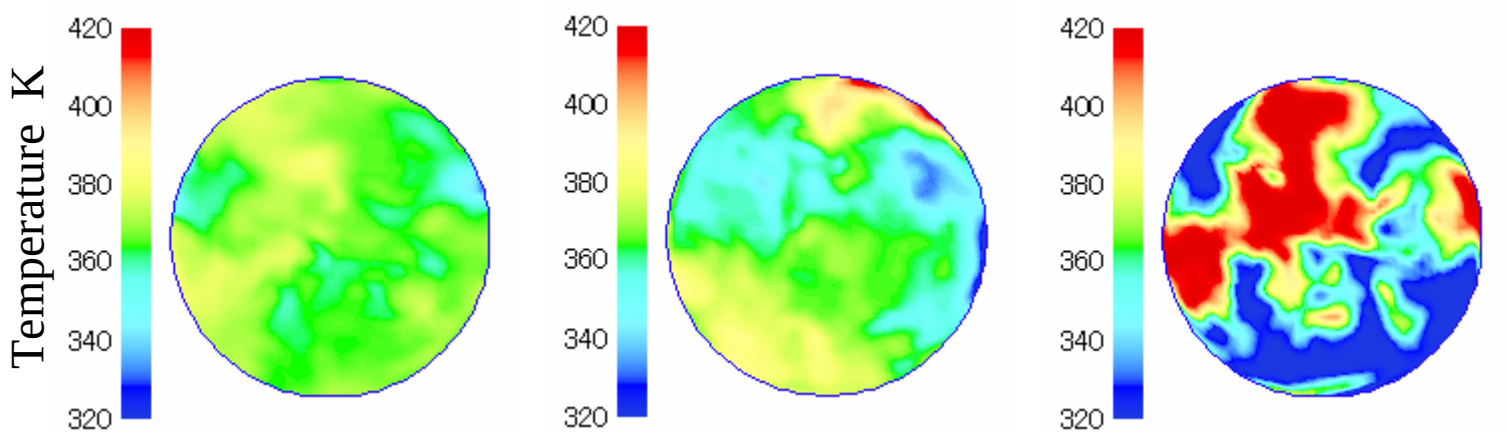
local
heat release
rate





Temperature (upper) and local heat release rate (lower) at the peak time of total heat release rate; average equivalence ratio = 0.4 without EGR

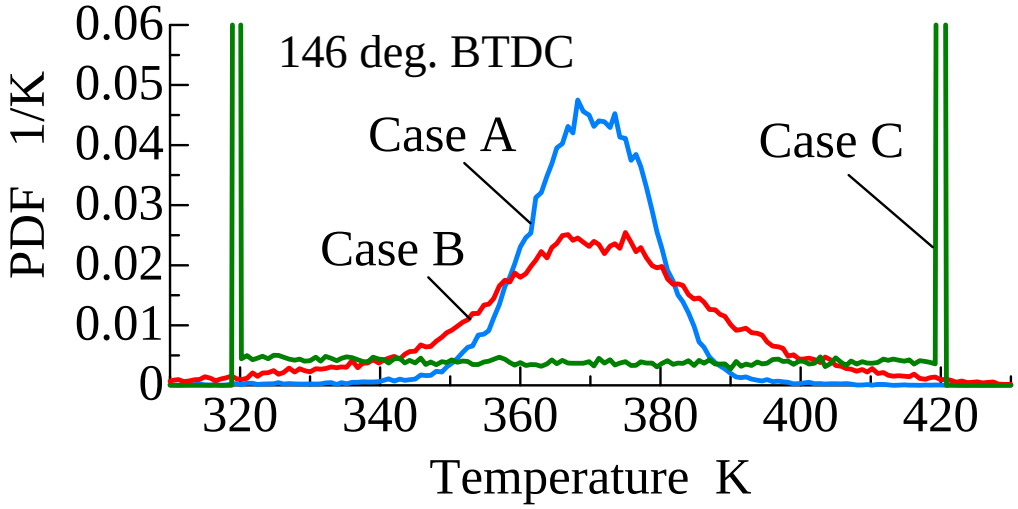
Heterogeneous Field of Temperature Distribution



ΔT_{RMS} = 10 K

ΔT_{RMS} = 20 K

ΔT_{RMS} = 43 K

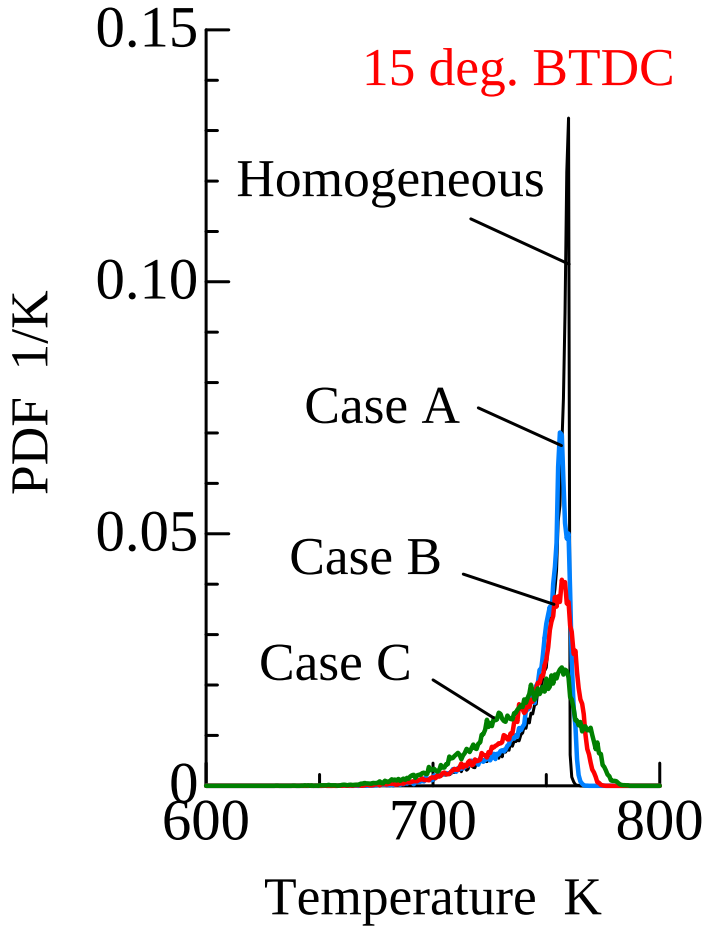


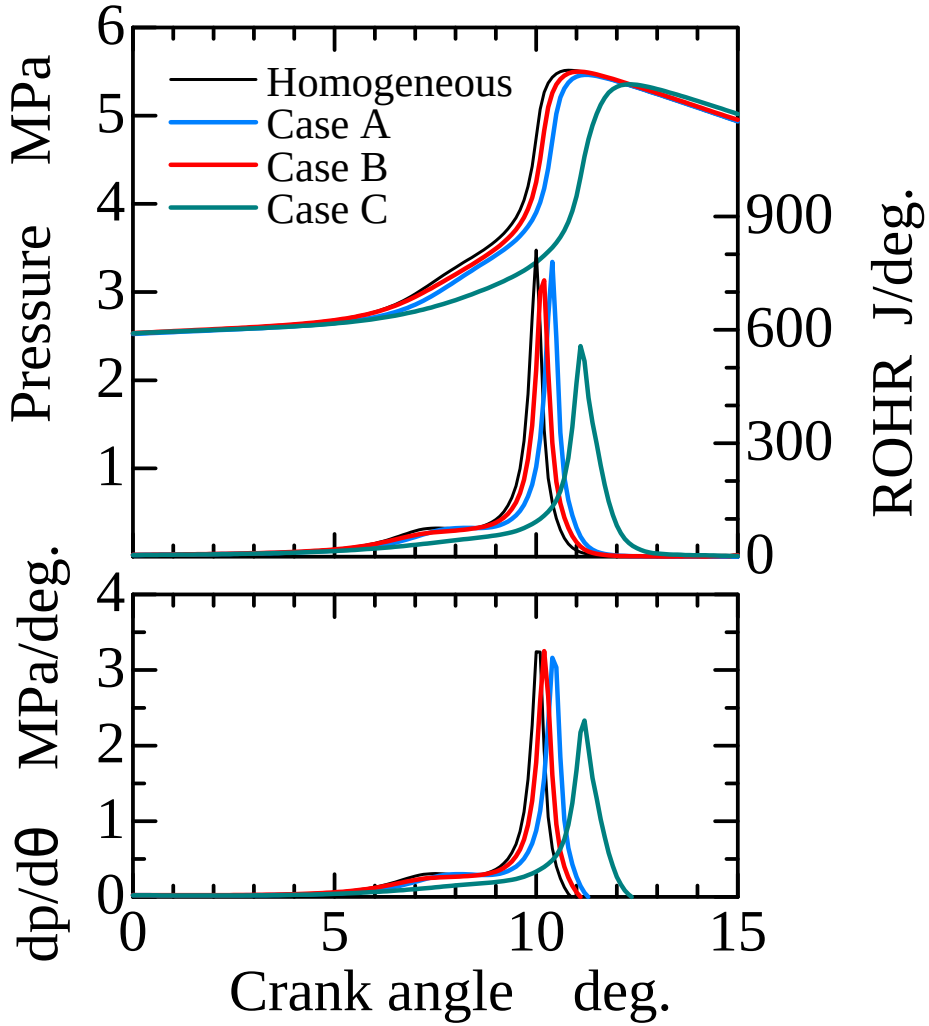
Average temperature:
370 K

EGR ratio:
0.4 , homogeneous

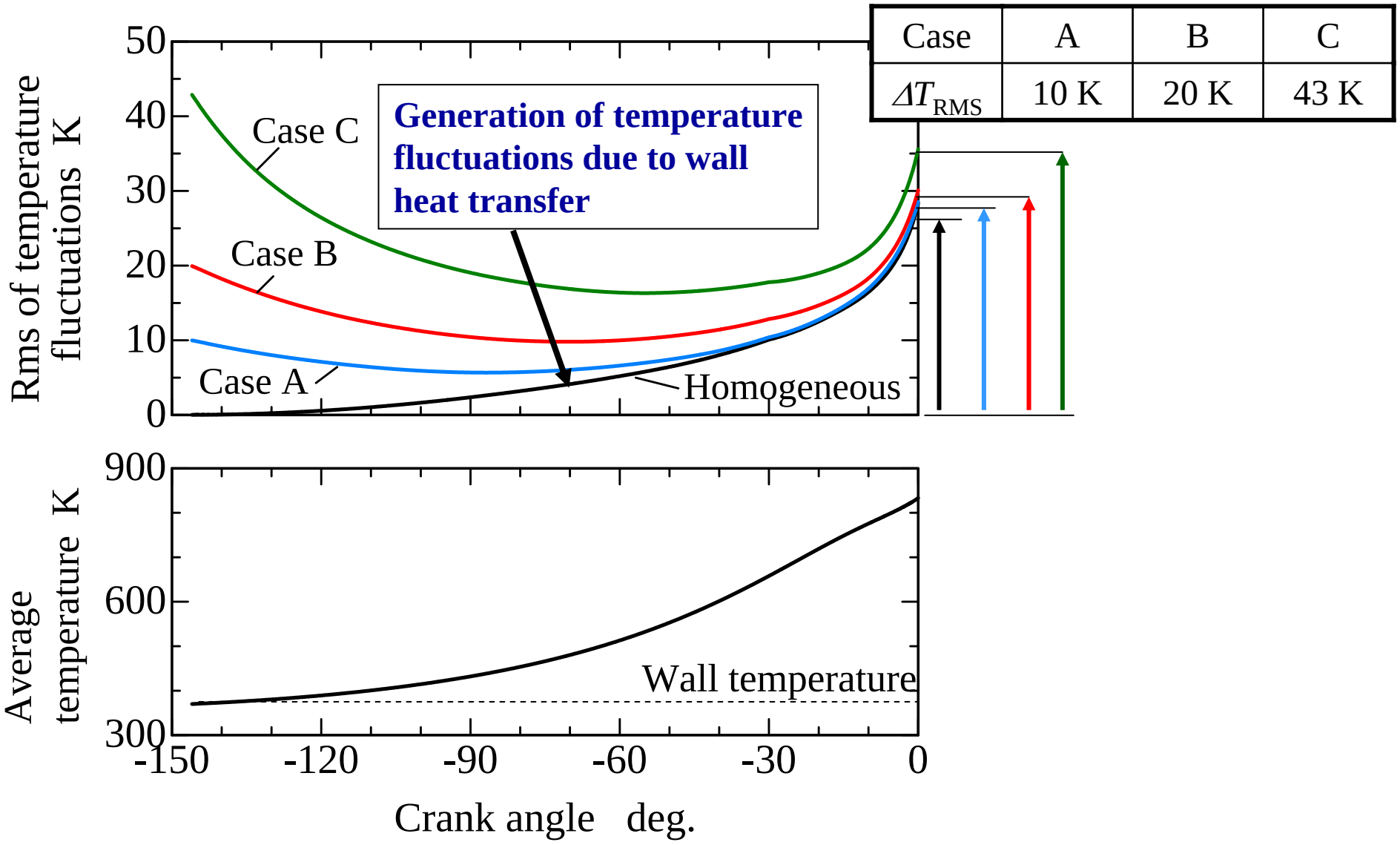
Equivalence ratio:
1.0 , homogeneous

Case	A	B	C
T_{RMS}	10 K	20 K	43 K



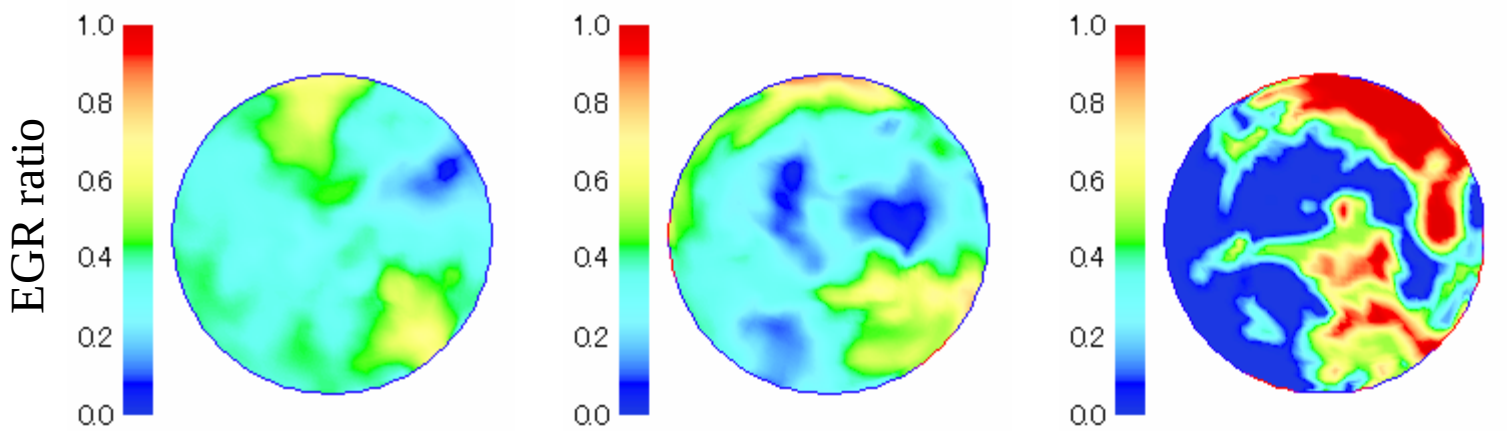


Time histories of cylinder pressures, total heat release rates and *dp/dθ* calculated for three different initial temperature distributions



Time history of temperature fluctuation during compression

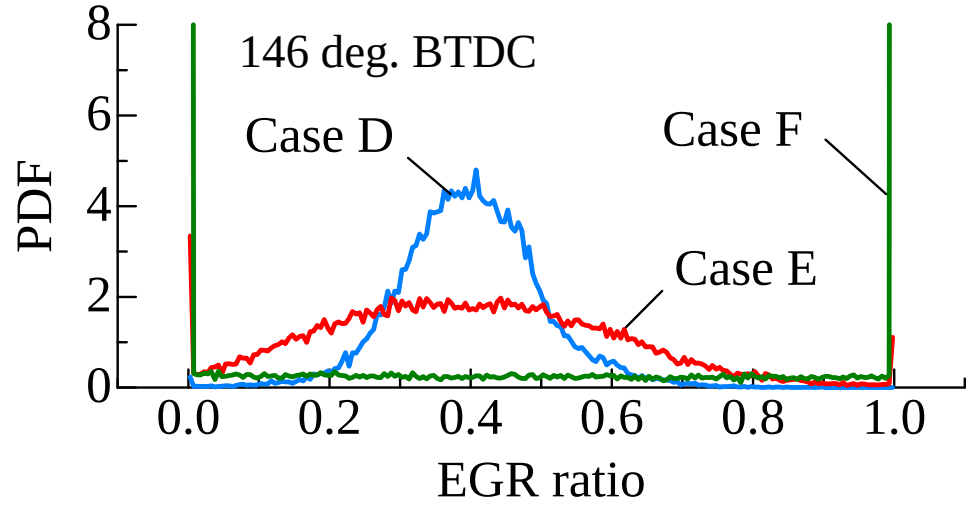
Heterogeneous Field of EGR gas



Case D
$\Delta EGR_{RMS} = 0.1$

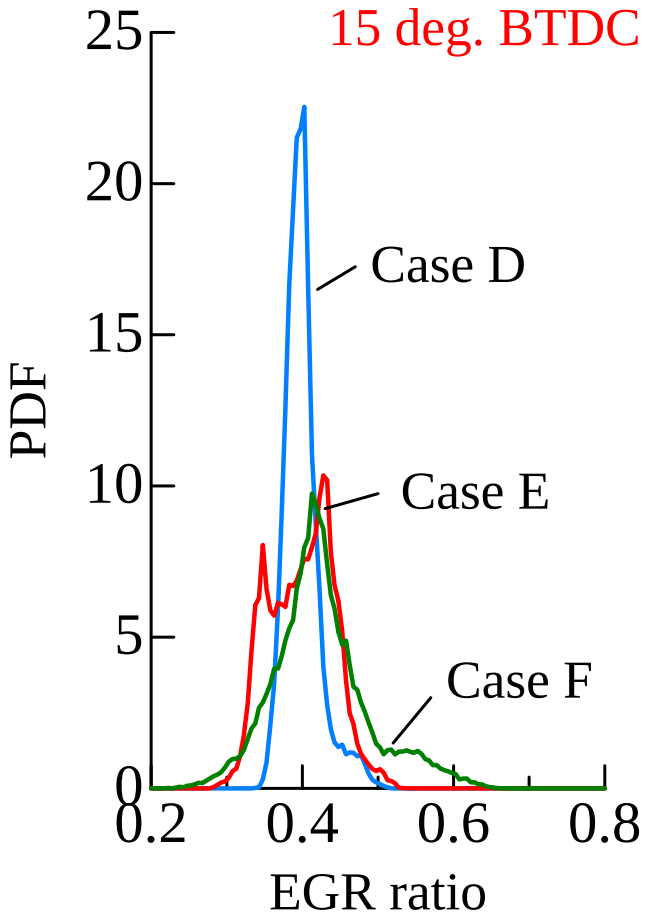
Case E
$\Delta EGR_{RMS} = 0.2$

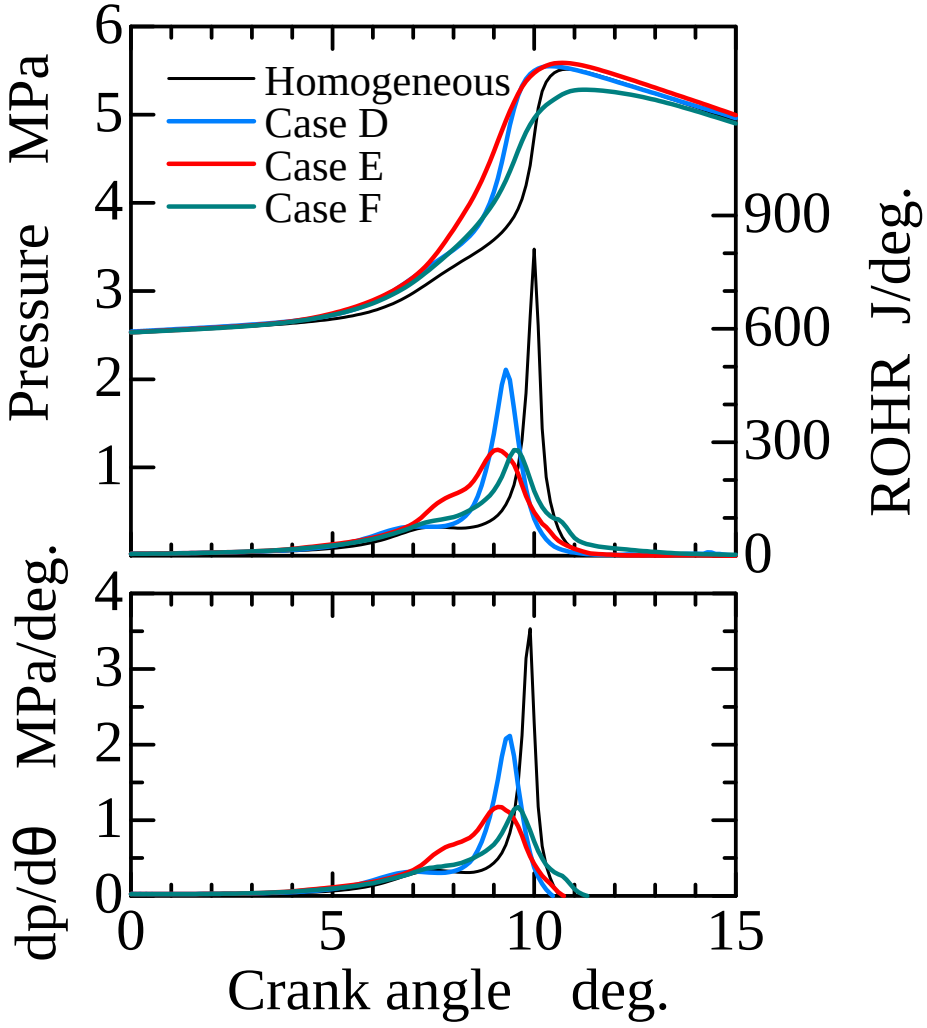
Case F
$\Delta EGR_{RMS} = 0.45$



Initial temperature:
370 K , Homogeneous
Equivalence ratio:
1.0 , homogeneous
EGR ratio:
0.4 (cylinder average)

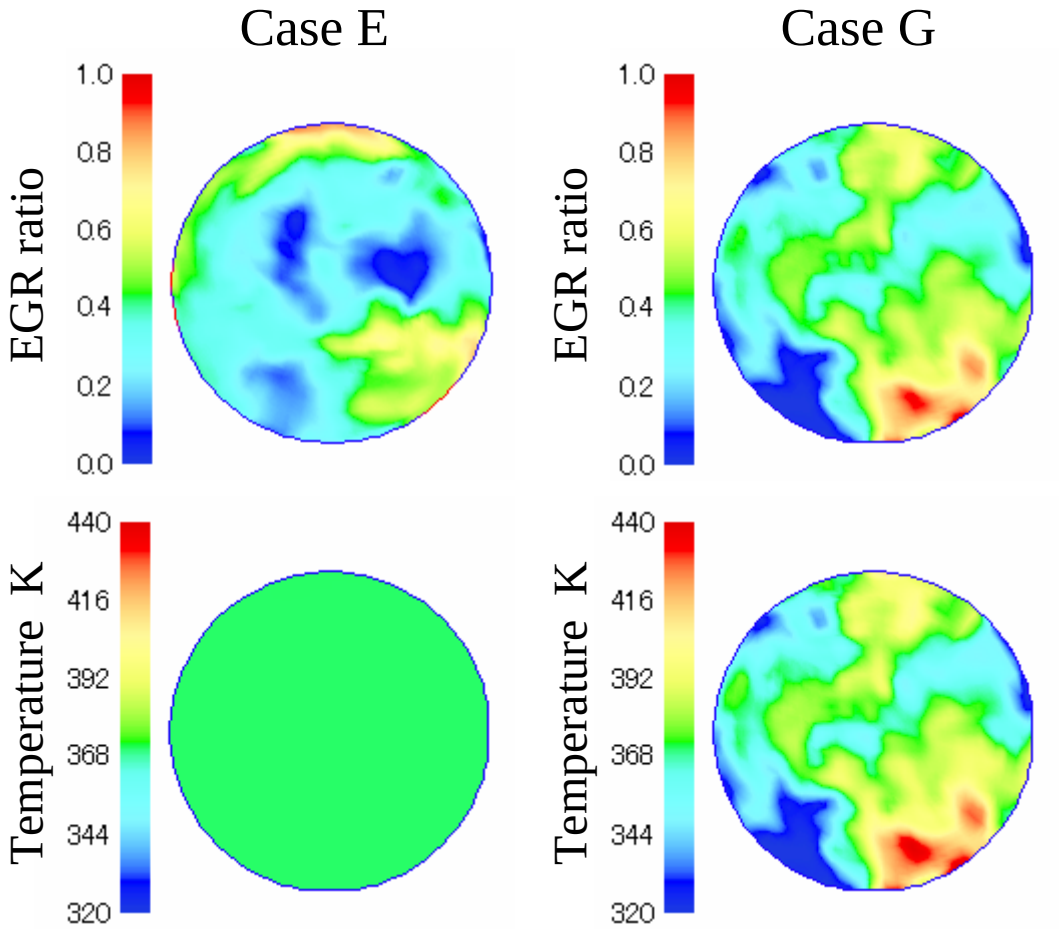
Case	D	E	F
EGR_{RMS}	0.1	0.2	0.45





Time histories of cylinder pressures, total heat release rates and $dp/d\theta$ calculated for three different initial EGR distributions; average ϕ =1.0, average EGR ratio = 0.4

Combined Effect of EGR and Temperature Distributions

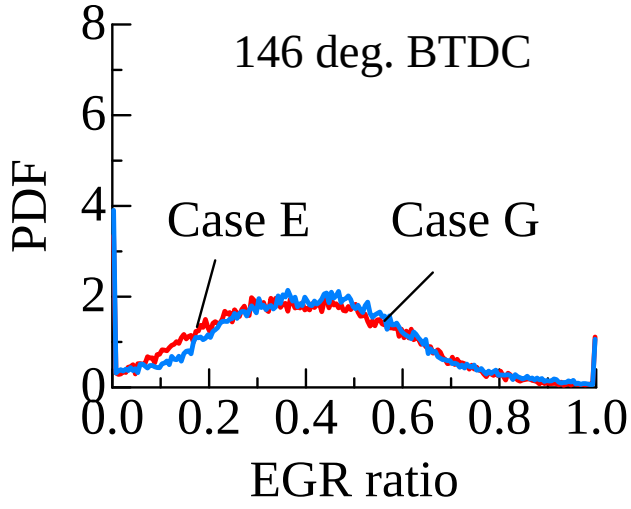


T_{MIX}= 370 K

T_{EGR}= 370 K

T_{MIX}= 330 K

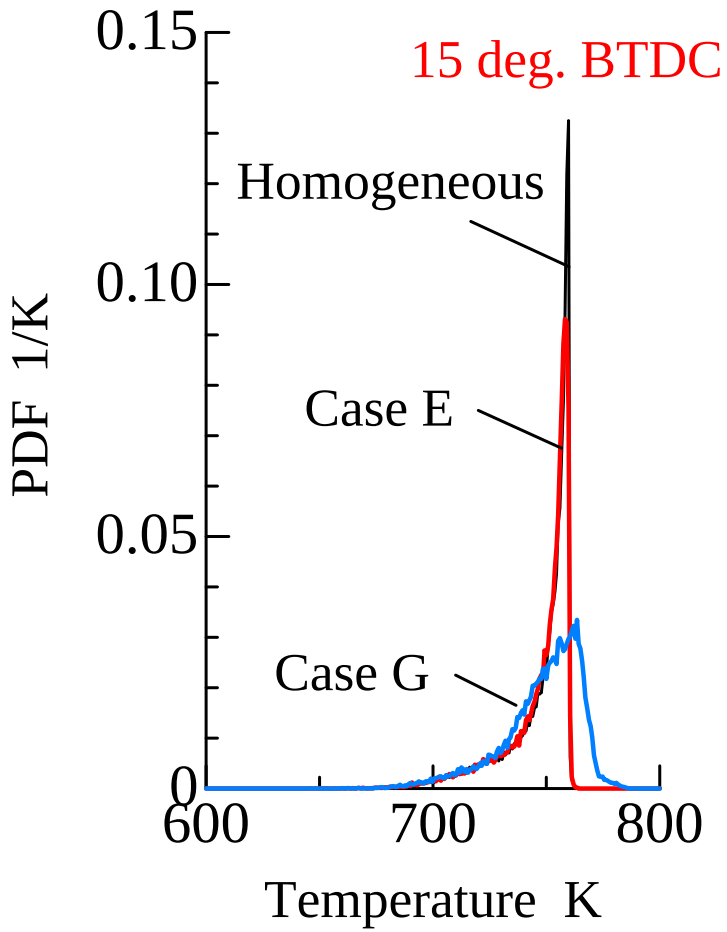
T_{EGR}= 430 K

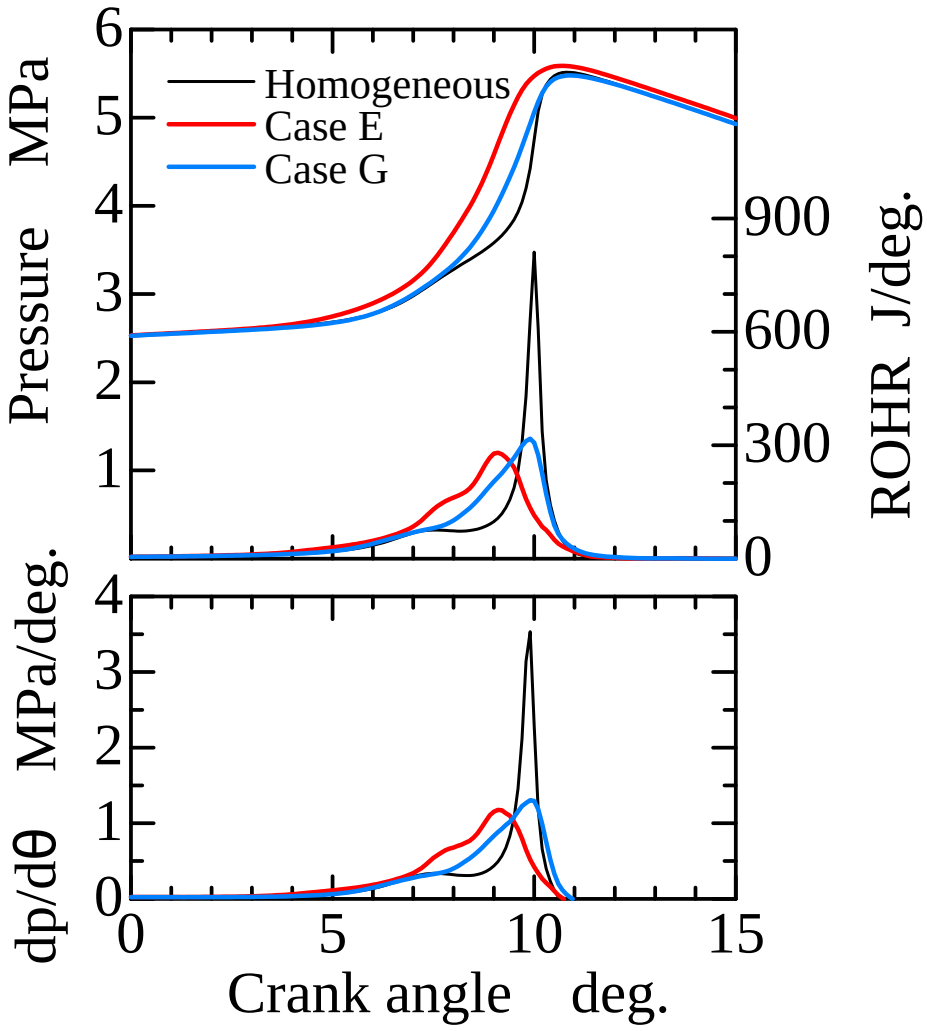


EGR_{RMS} = 0.2

Average EGR ratio:
0.4
Equivalence ratio:
1.0 , Homogeneous
Average temperature:
370 K

Case	E	G
T_{MIX}	370 K	330 K
T_{EGR}		430 K



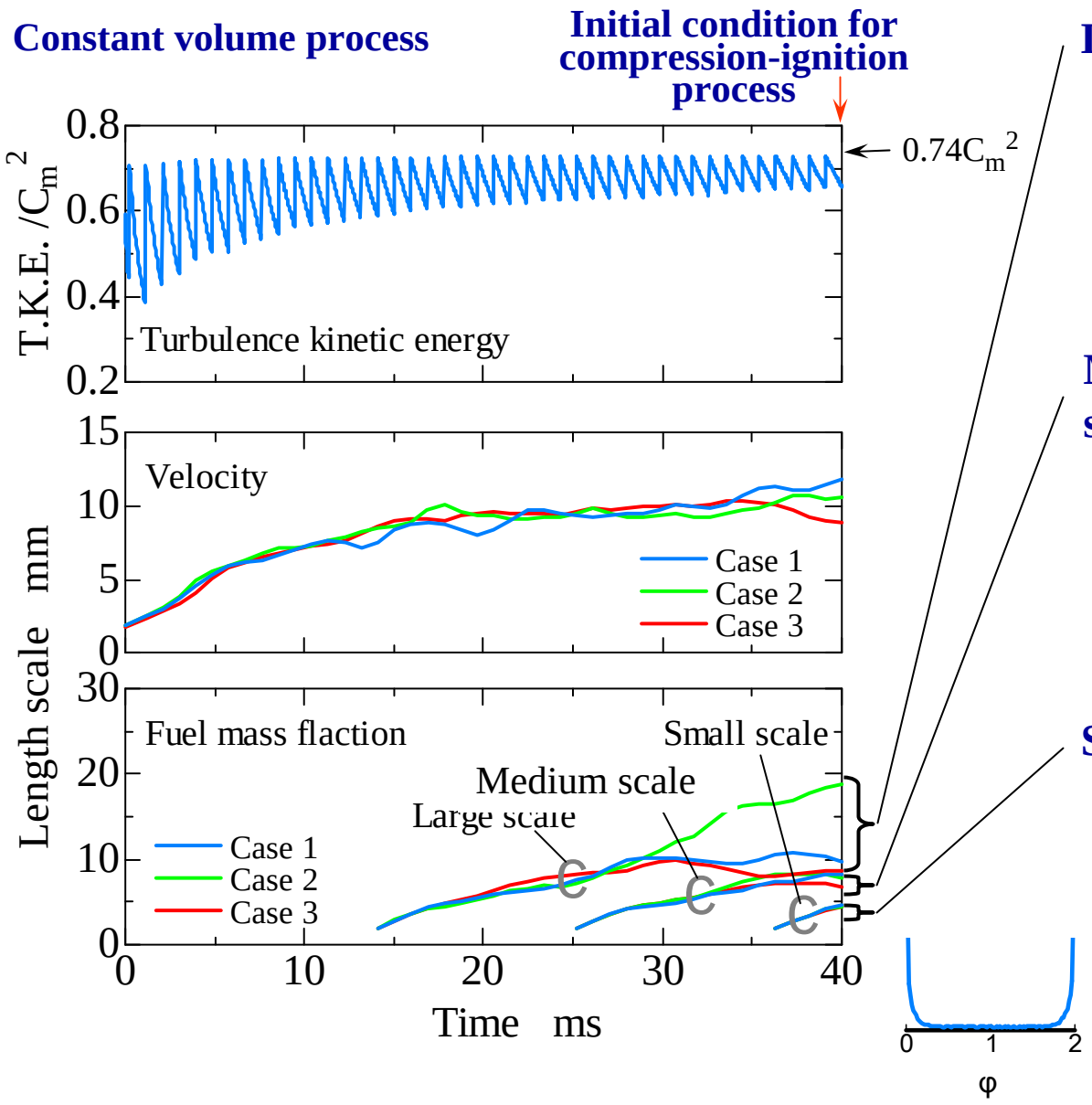


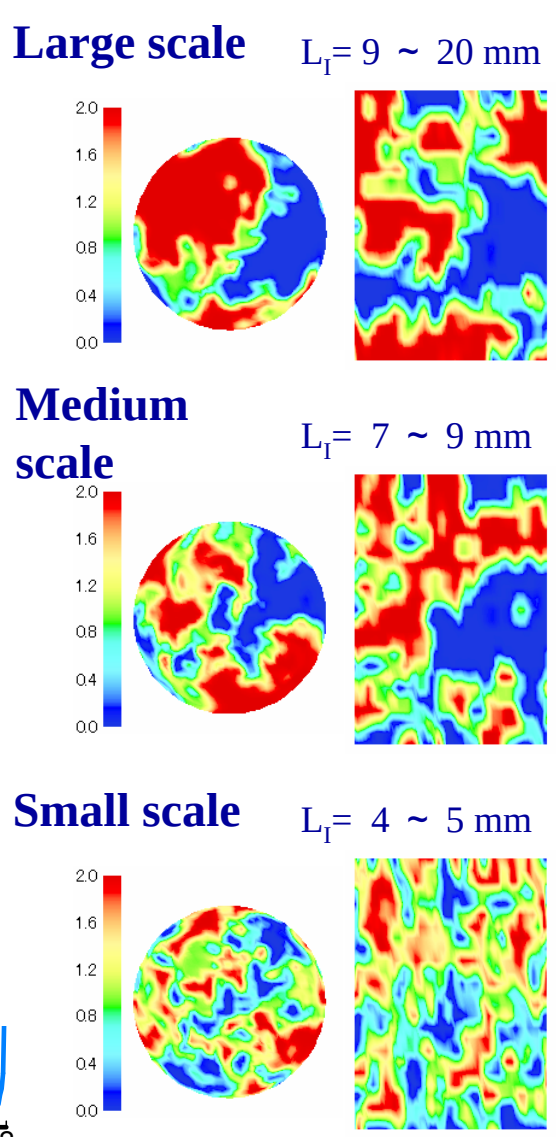
Time histories of cylinder pressures, total heat release rates and *dp/dθ* calculated for different combinations of initial EGR and temperature distributions

CONCLUSIONS

- Heterogeneity in fuel distribution contributes to reduce abrupt heat release in PCCI combustion.
- Not only the rms value but also the length scale of fuel distribution may be important factors to control the heat release rate of the PCCI combustion.
- Heterogeneous EGR gas distribution gives a similar effect.
- Non-uniform temperature distribution does not give a considerable effect, compared to heterogeneous fuel or EGR gas distribution.

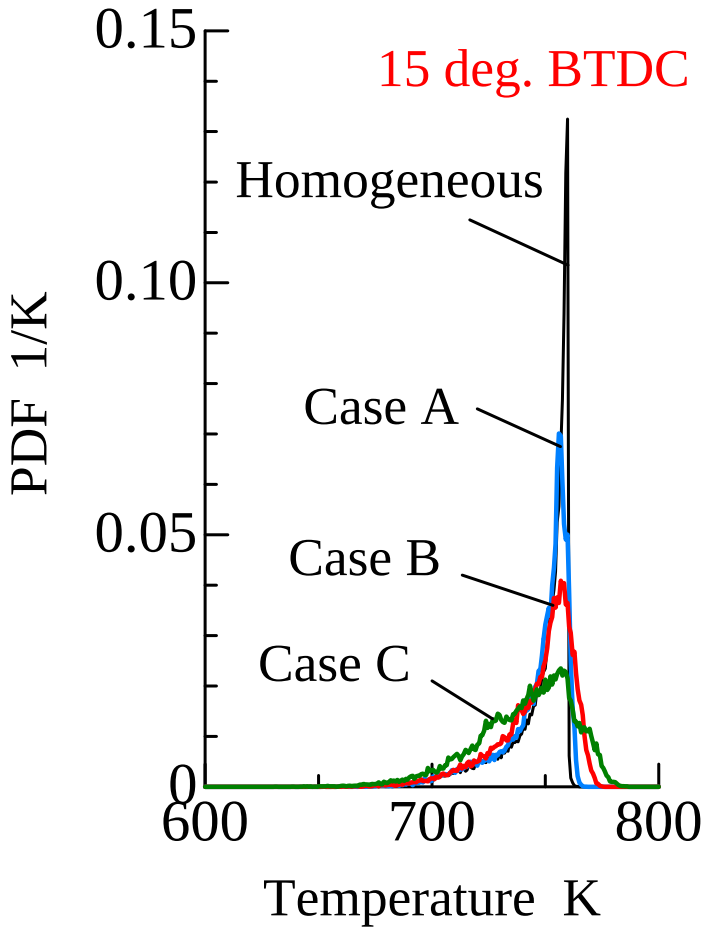
Generating Different Initial Fields of Fuel Mass Fraction

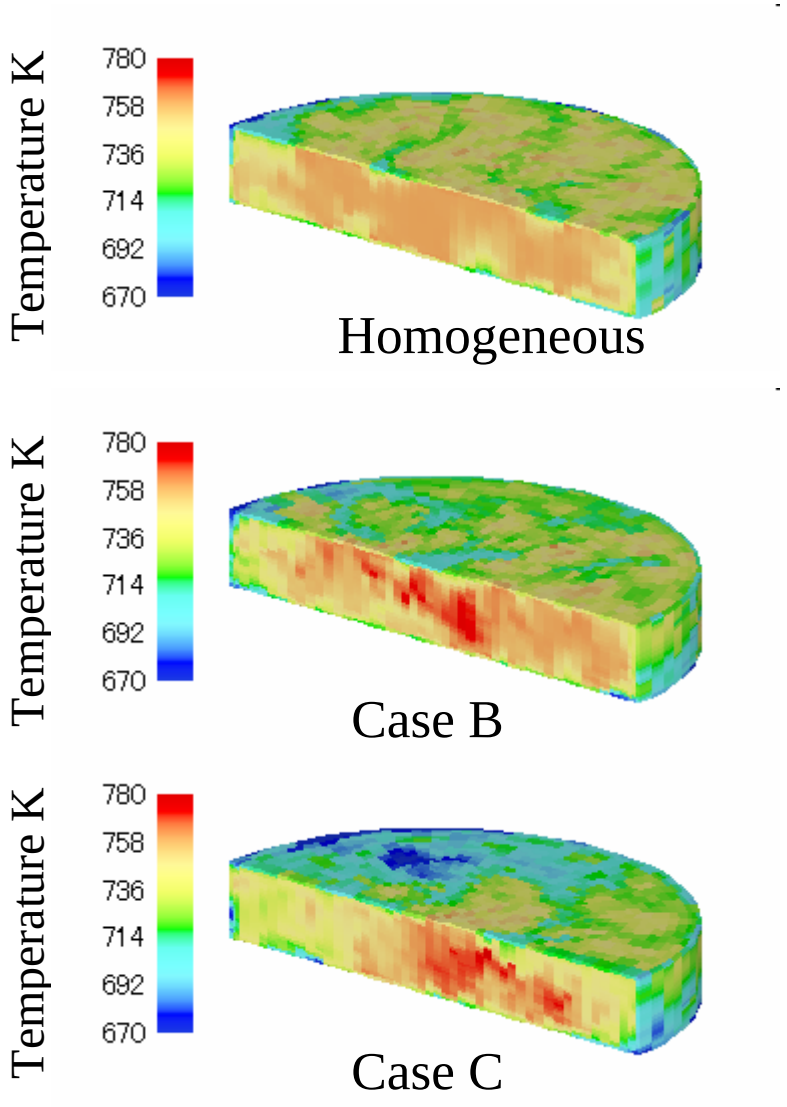




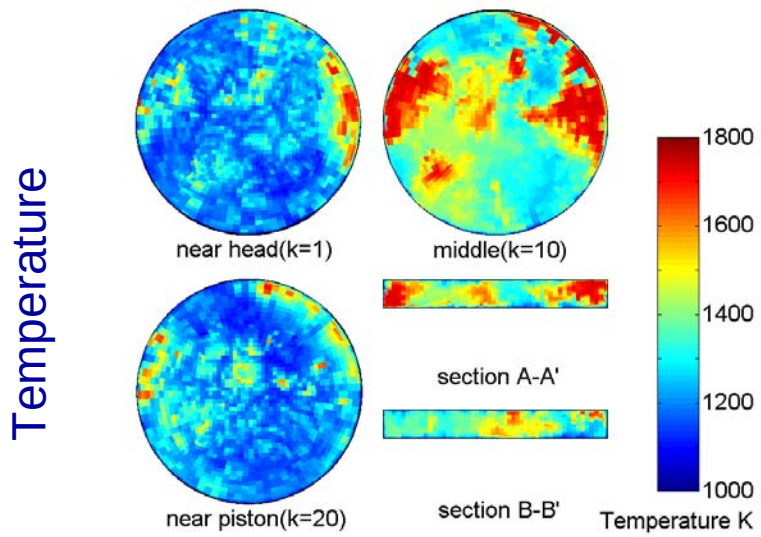
Homogeneous EGR ratio = 0.4

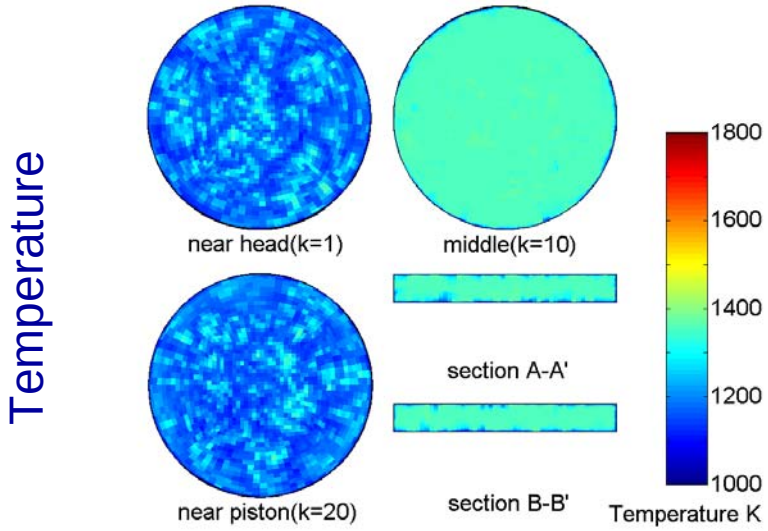
Case	A	B	C
T_{RMS}	10 K	20 K	43 K

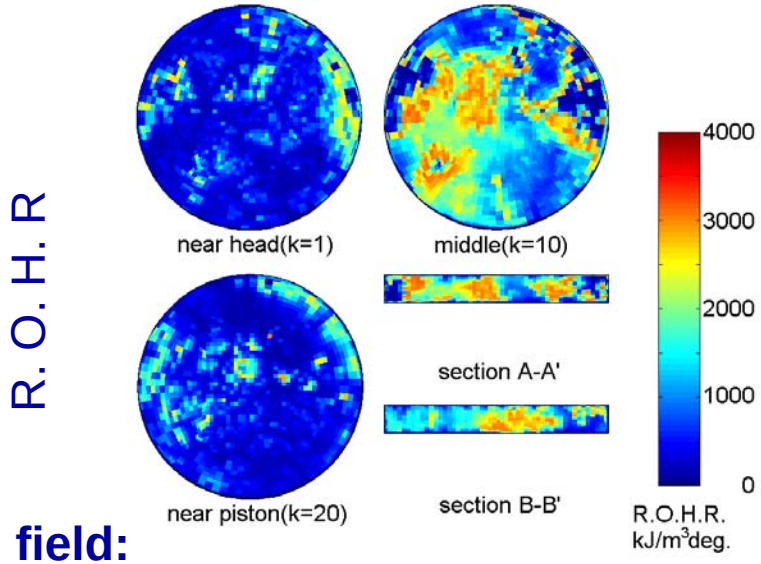




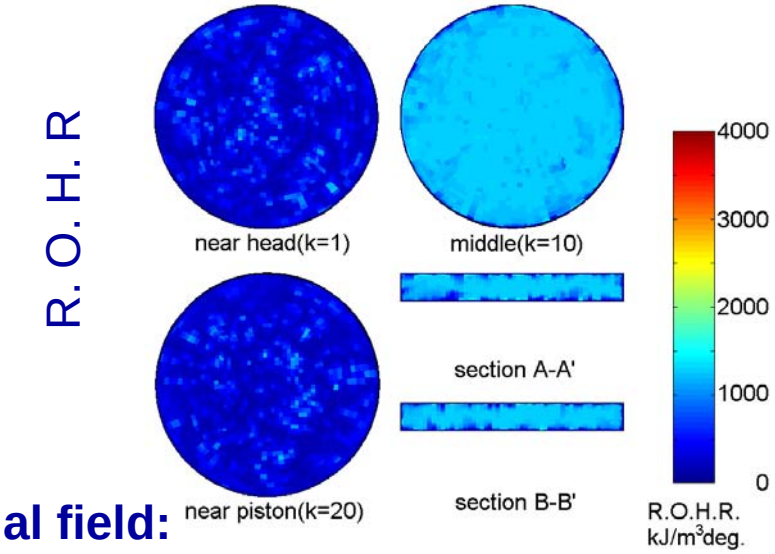
temperature fields at 15 deg. BTDC for three different initial temperature distributions







Initial field:
heterogeneous EGR and temperature



Initial field:
homogeneous EGR and temperature

Temperature and ROHR at hot-flame peak time