LES of turbulent combustion in a spark assisted HCCI engine

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Sponsors: KC-FP (competence center for combustion process), STEM

Outline

- Background
- Experimental setup
- LES Model
- Computational conditions
- Results and Discussions
- Conclusions

Background

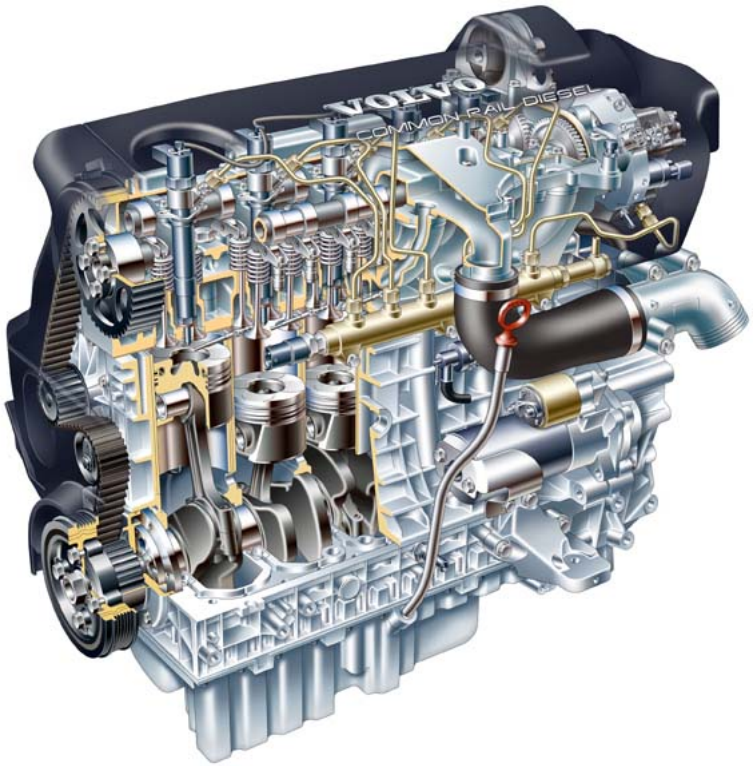
- Homogeneous charge compression ignition (HCCI) combustion
  - High efficiency, low emssion
  - Difficult to control

- Spark assisted HCCI combustion (SACI)
  - SACI controls the ignition timing of HCCI
  - Improve low load SI engine performance
  - SI flame, HCCI ignition interaction
  - Operation range narrow

- SACI engine experiments show that
  - Spark ignition time has to be adjusted with load: low load earlier ignition
  - Swirl has significant effect on SACI

- Objectives of this study
  - Using LES to simulate the SACI process
  - To improve the understanding of the physical SACI process

Engine setup



Volvo D5 engine

Bore	81 mm
Stroke	93.2 mm
Compression ratio	12
Engine speed	1200 rpm
Fuel	ethanol
Lambda	1.3

Port fuel injection
Flat piston

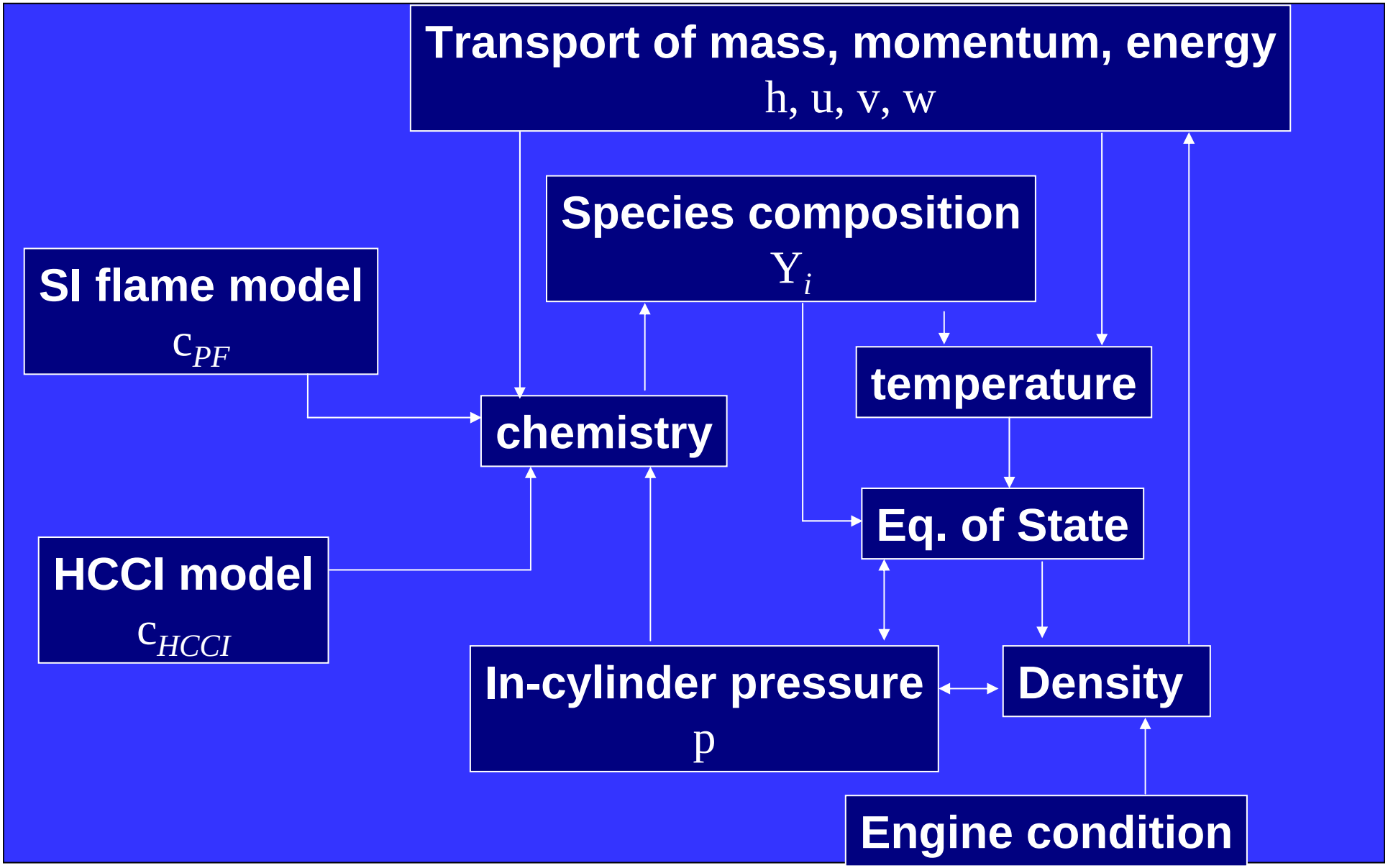
Hot residual gas trapped using NVO	ca. 50%

SACI model

- Auto-ignition model
  - Identical to the HCCI model
  - A reaction progress variable: accumulative heat release
  - Detailed chemistry tabulation as function of enthalpy, pressure and reaction progress variable

- Spark ignited flame front model
  - Flame front marker: a second reaction progress variable
  - Flame front propagation speed incorporated to the model as source term of the progress variable transport equation
  - Flame surface density model

SACI model


Transport of mass, momentum, energy
h, u, v, w
Species composition
Y_i
SI flame model
c_{PF}
temperature
chemistry
Eq. of State
HCCI model
c_{HCCI}
In-cylinder pressure
p
Density
Engine condition

Computational conditions

- Initial conditions from intake to 290 CAD
  - Simulated using LES for the real engine configuration
  - u, v, w, T, p, ϱ

- Parameter study from 290 CAD towards ATDC
  - Varying the initial mean temperature
  - Varying the temperature variance
  - Varying level of turbulence
  - Ignition properties;
    - SACI – auto-ignition combined with flame propagation
    - HCCI – only auto-ignition

In-House code: LES4E

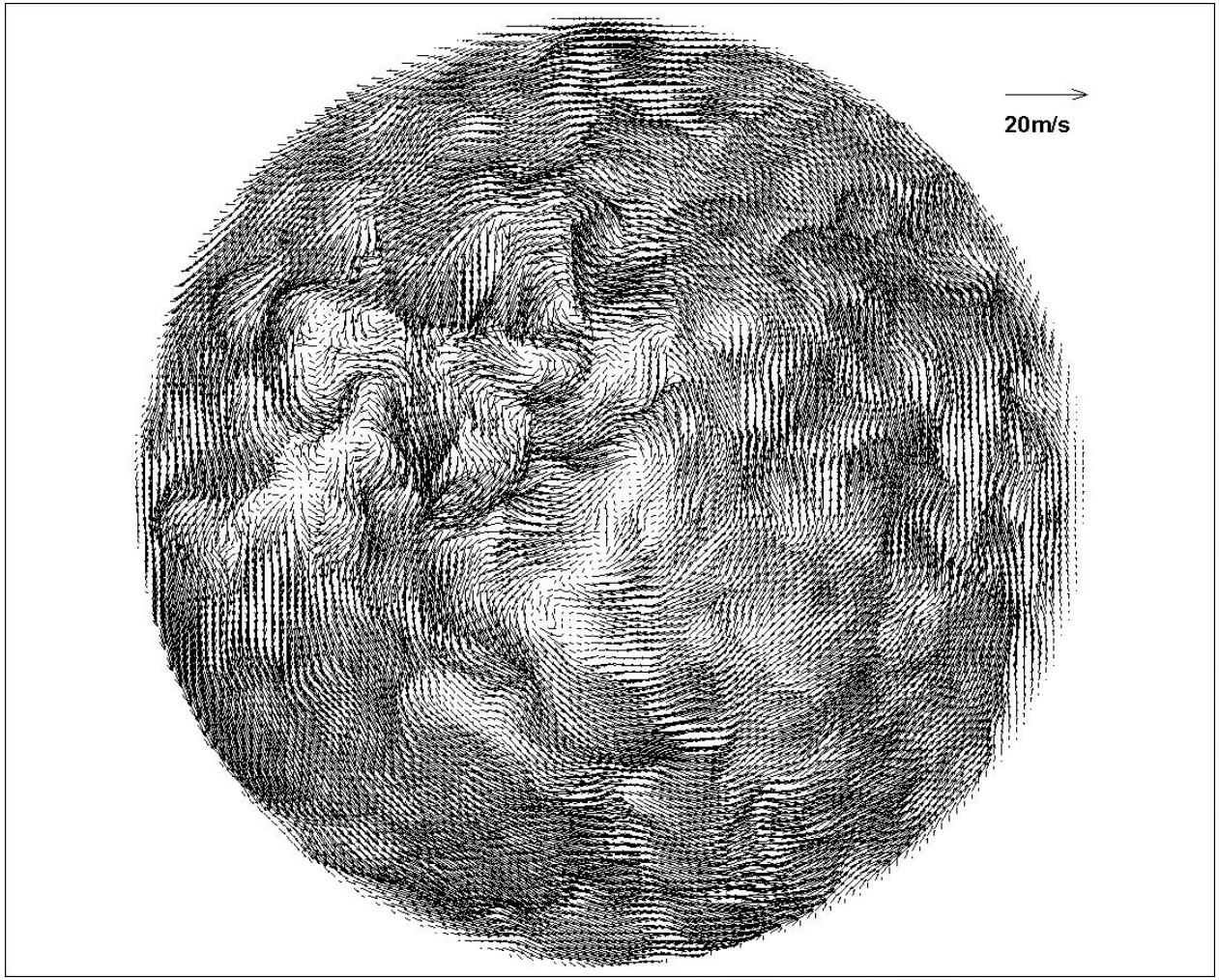
Physical model

- Navier-Stokes equations
- Low Mach number approximation
- Model for SACI combustion
- SGS model for momentum: SSM
- SGS model scalars: Smagorinsky model

Numerical Solver

- Staggered deforming grids
- Predictor/Corrector time integration
  - Predictor 2nd order Adam-Bashforth
  - Corrector 2nd order Crank-Nicolson
- Spatial discretization
  - 5th order WENO scheme for the convective terms
  - 4th order central-difference-scheme for the other terms

Initial velocity field @ 290 CAD



Generation of initial field

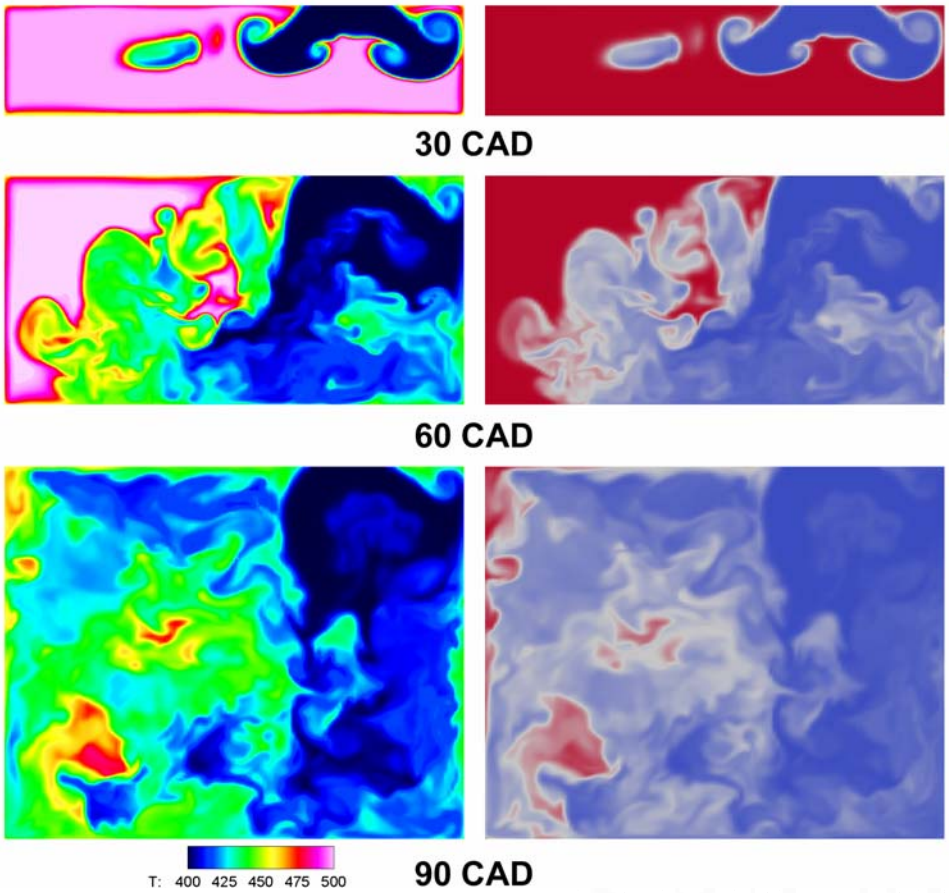
- LES of the intake and compression stroke simulating the mixing of intake fuel/air mixture with the hot residual gas

- The flow field at 290 CAD (70 CAD bTDC) is used as the baseline initial field for the SACI simulation

- The initial field is perturbed for sensitivity and parametric study

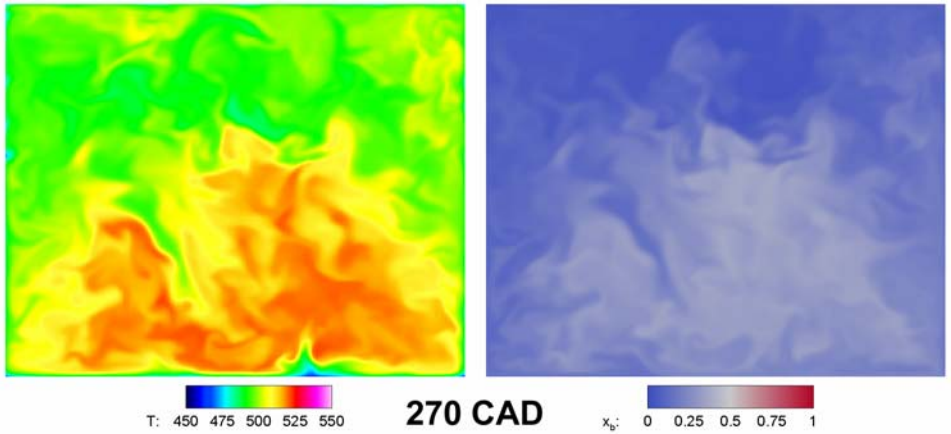
LES Temperature & Residual Gas Fraction

Intake



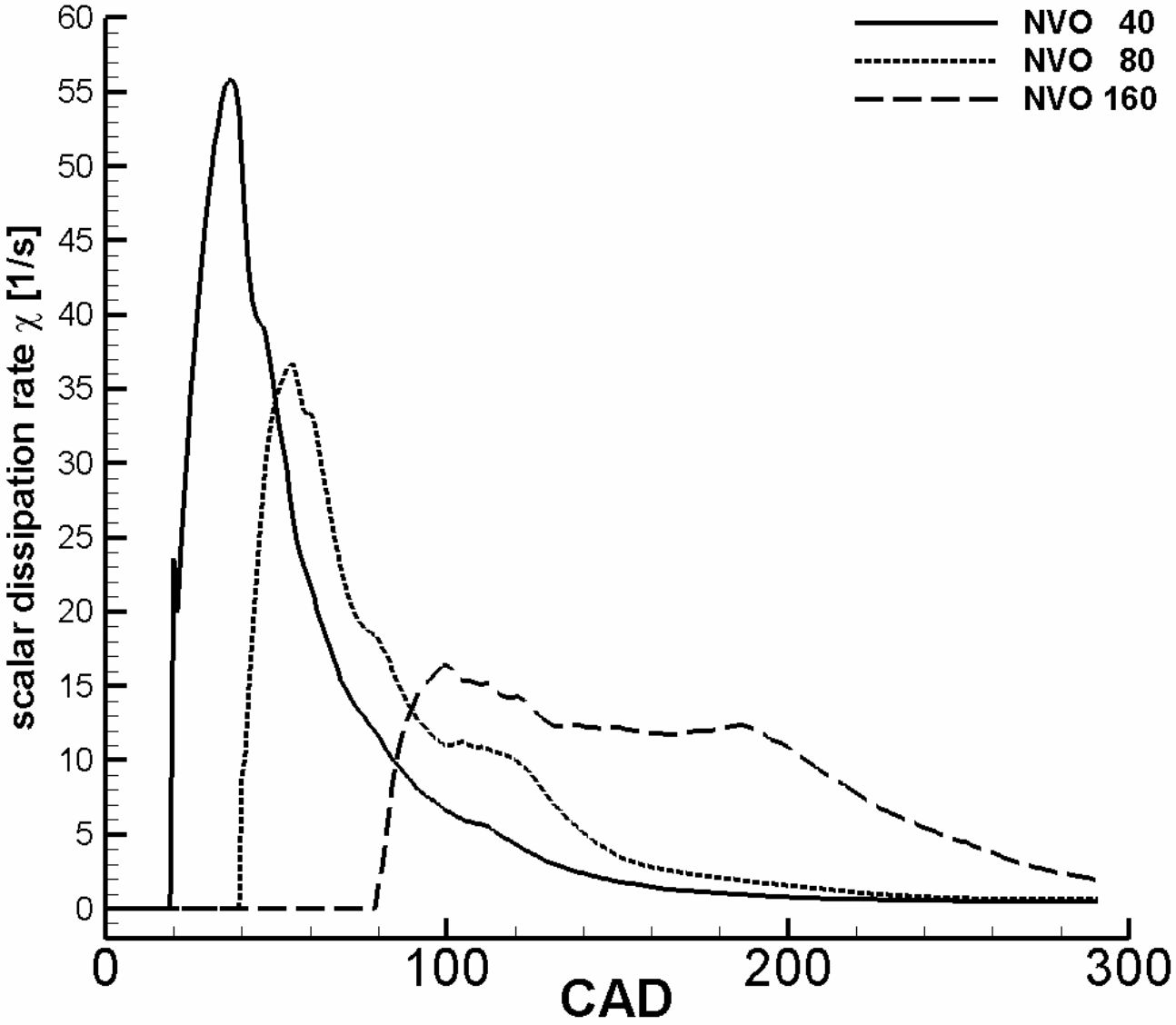
Temp ResGas Fraction

Compression



Temp ResGas Fraction

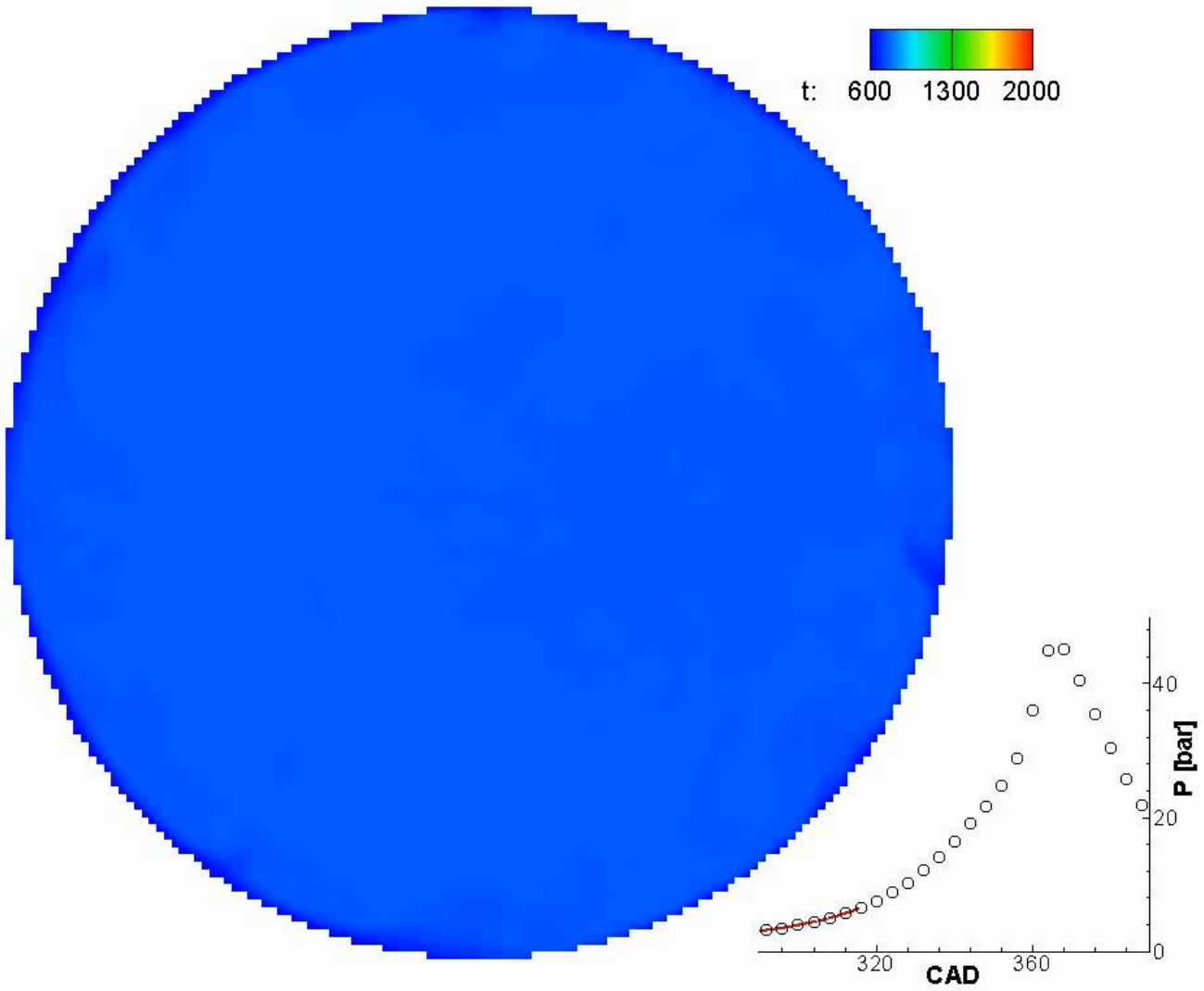
Scalar Dissipation Rate of Residual Gas Fraction



Simulation cases

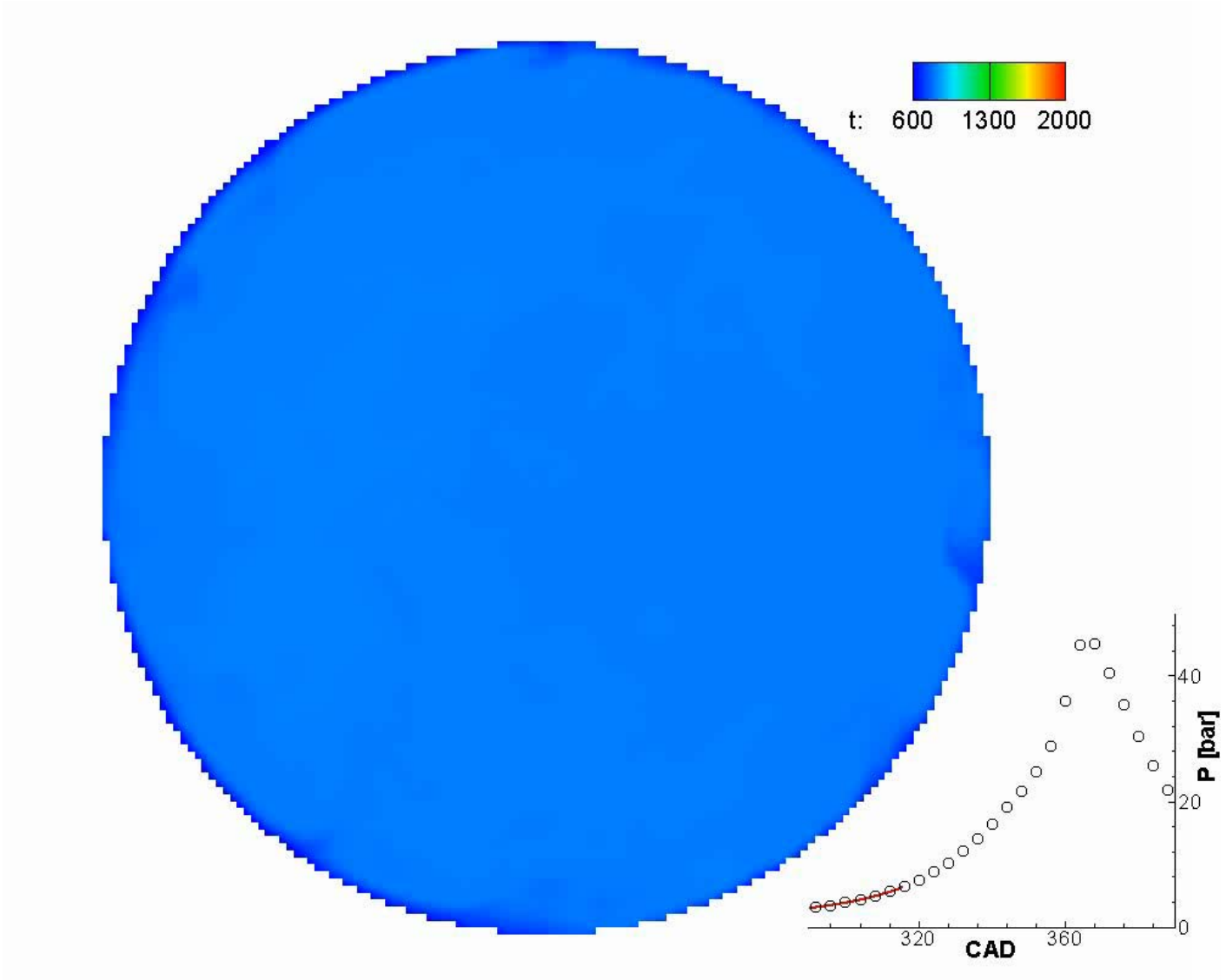
	@ 290 CAD			
cases	**<T> [K]**	**T' [K]**	**u' [m/s]**	**spark time [CAD]**
saci-1	**580**	**50**	**3.11**	**320**
saci-2	**620**	**20**	**3.11**	**320**
saci-3	**620**	**50**	**3.11**	**320**
saci-4	**650**	**20**	**3.11**	**320**
saci-5	**670**	**20**	**3.11**	**320**
saci-6	**650**	**20**	**0.50**	**320**
hcci-1	**620**	**20**	**3.11**	**–**
hcci-2	**650**	**20**	**3.11**	**–**
hcci-3	**670**	**20**	**3.11**	**–**

saci-2: 2D temperature and incylinder pressure



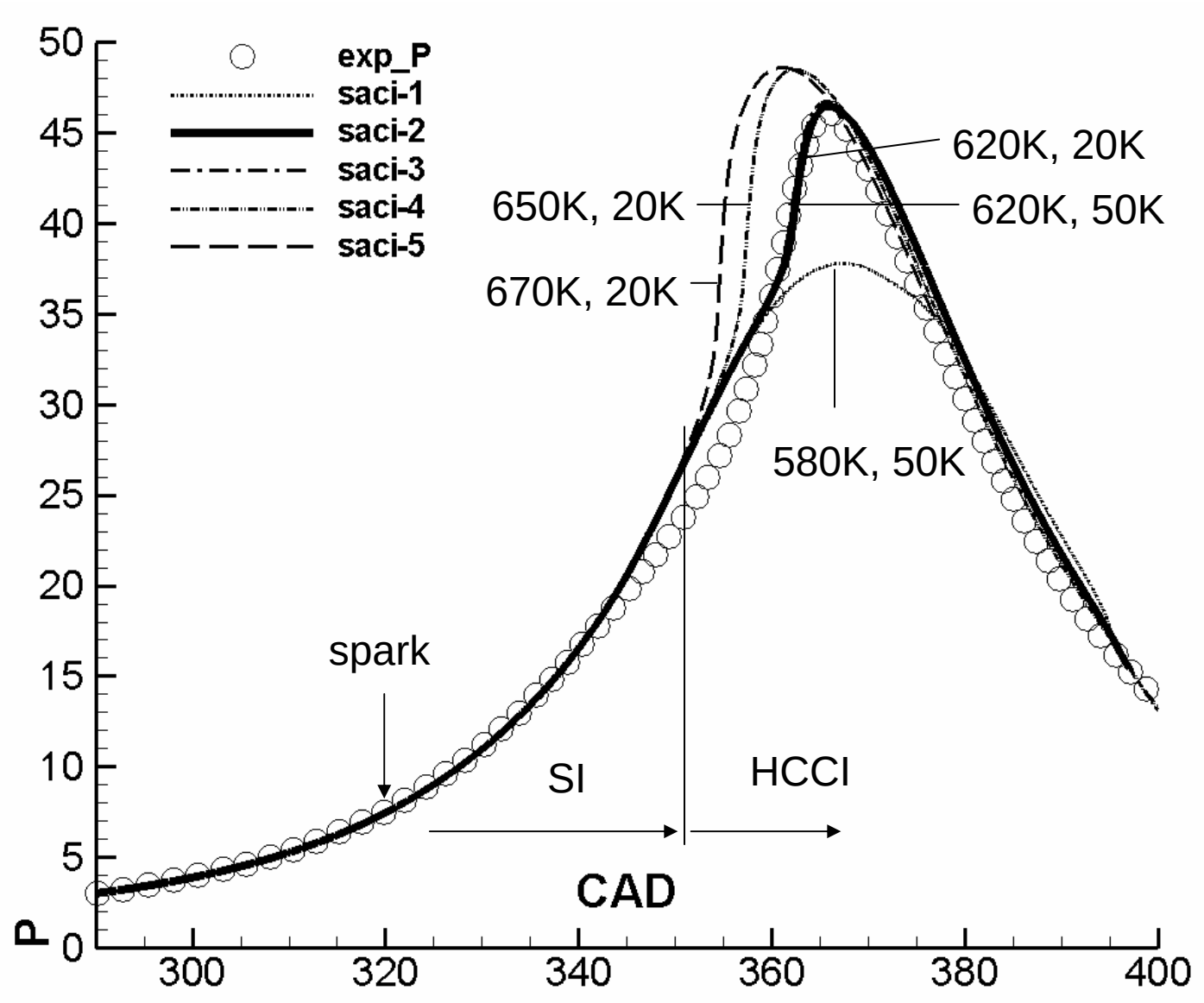
u’ = 3.1 m/s
T = 620 K
T’ = 20 K

saci-5: 2D temperature and incylinder pressure

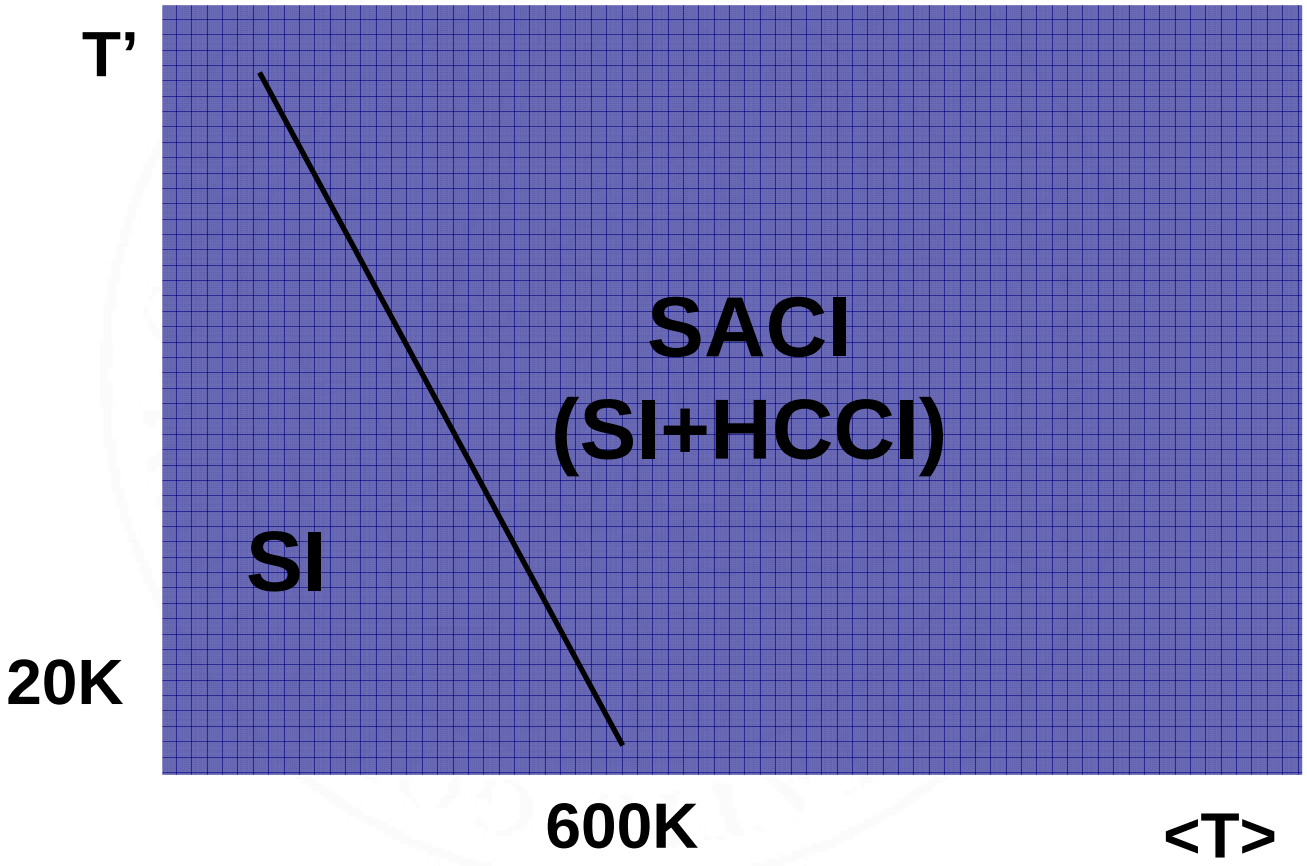


u’ = 3.1 m/s
T = 670 K
T’ = 20 K

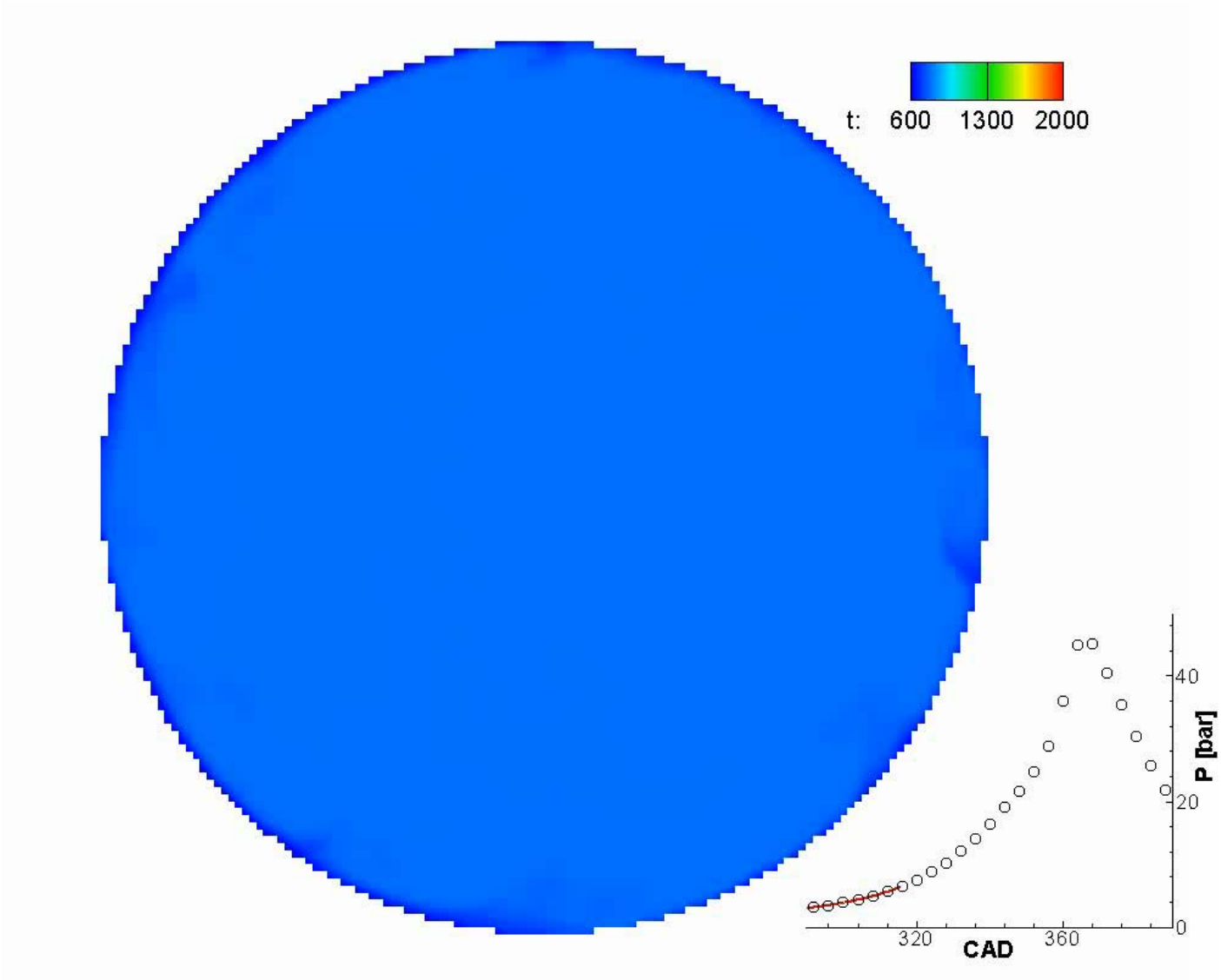
Incylinder pressure at different SACI conditions



Effect of initial temperature on SACI

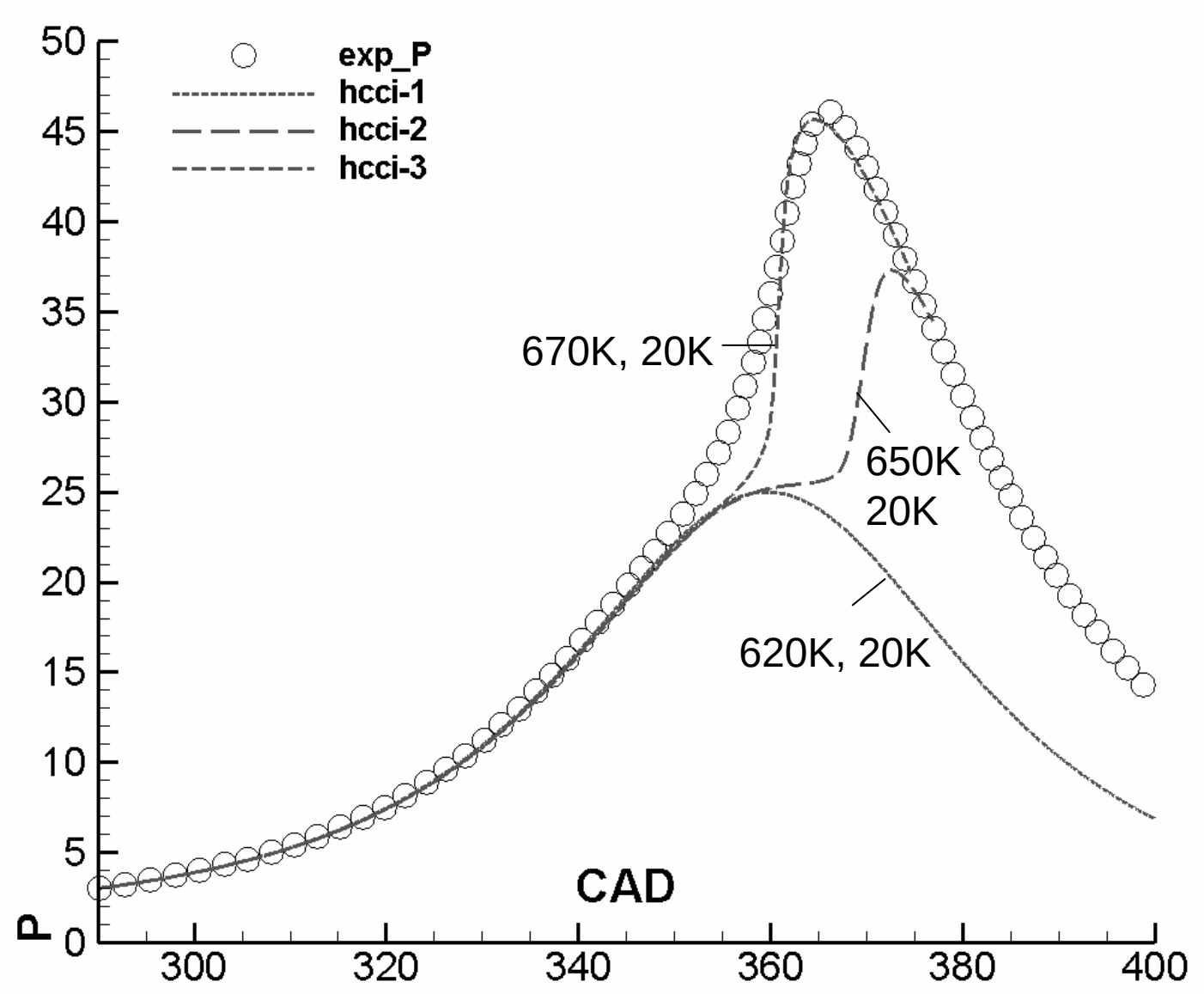


hcci-2: 2D temperature and incylinder pressure

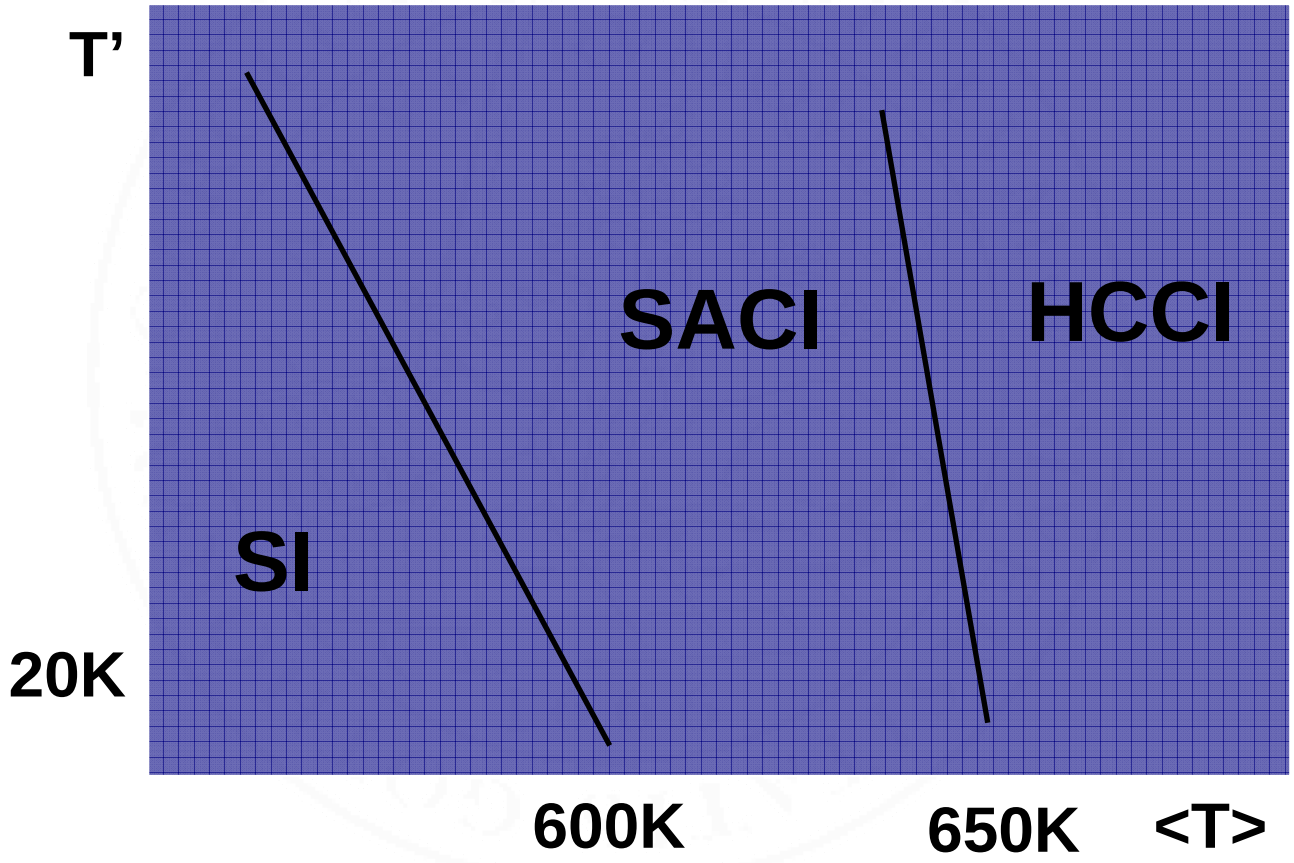


u’ = 3.1 m/s
T = 650 K
T’ = 20 K

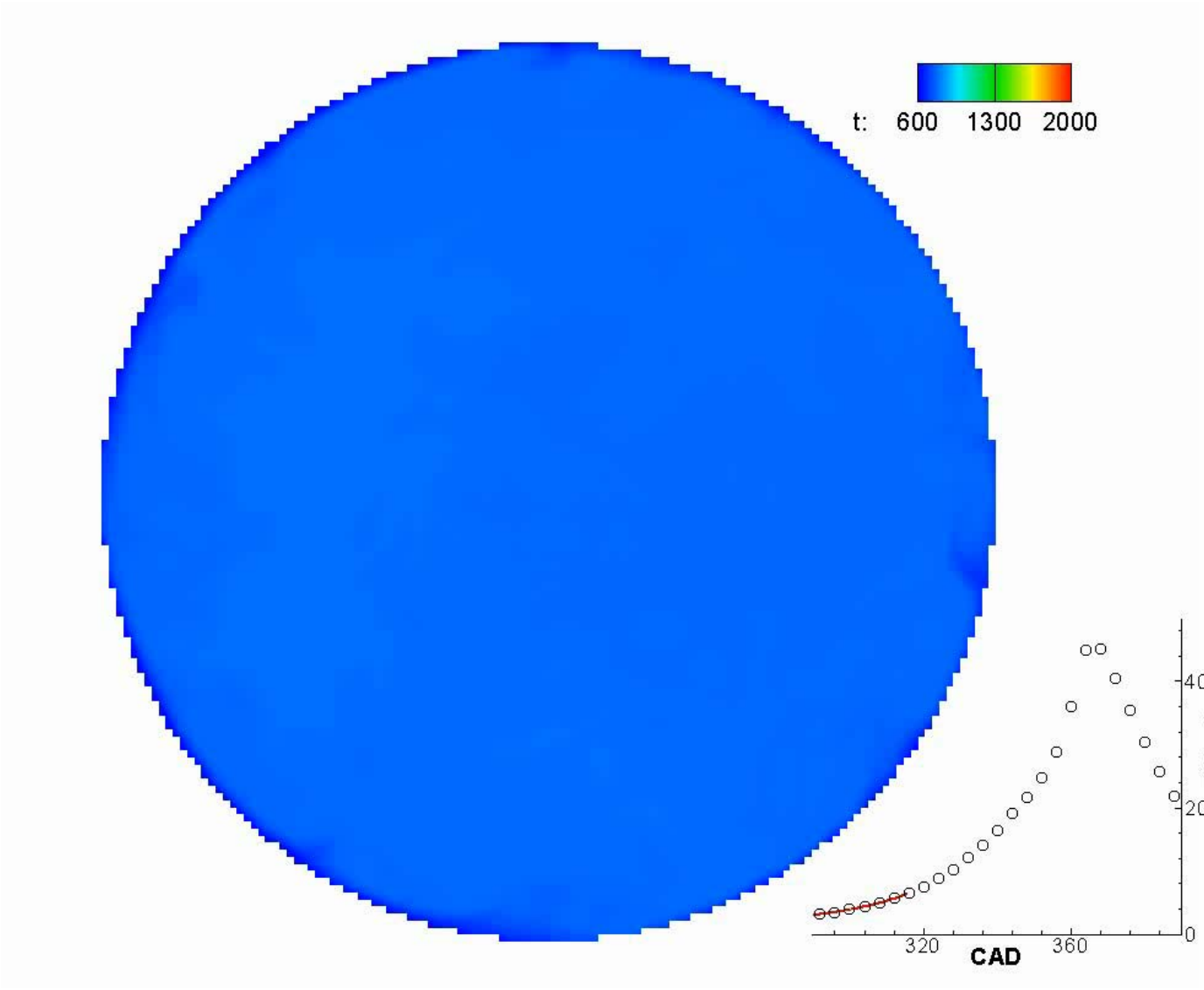
Incylinder temperature at different conditions



Temperature effect

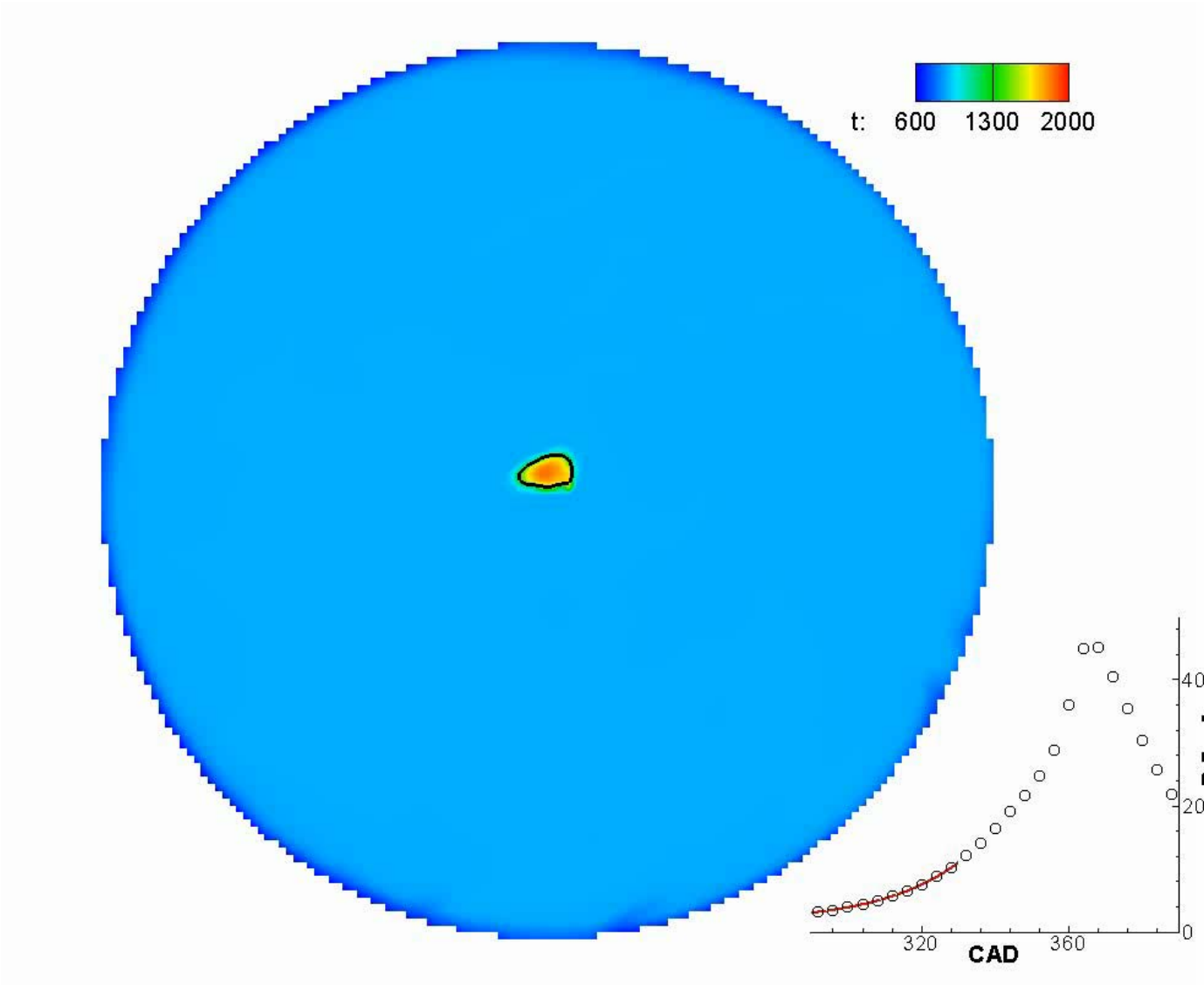


saci-4: 2D temperature and incylinder pressure



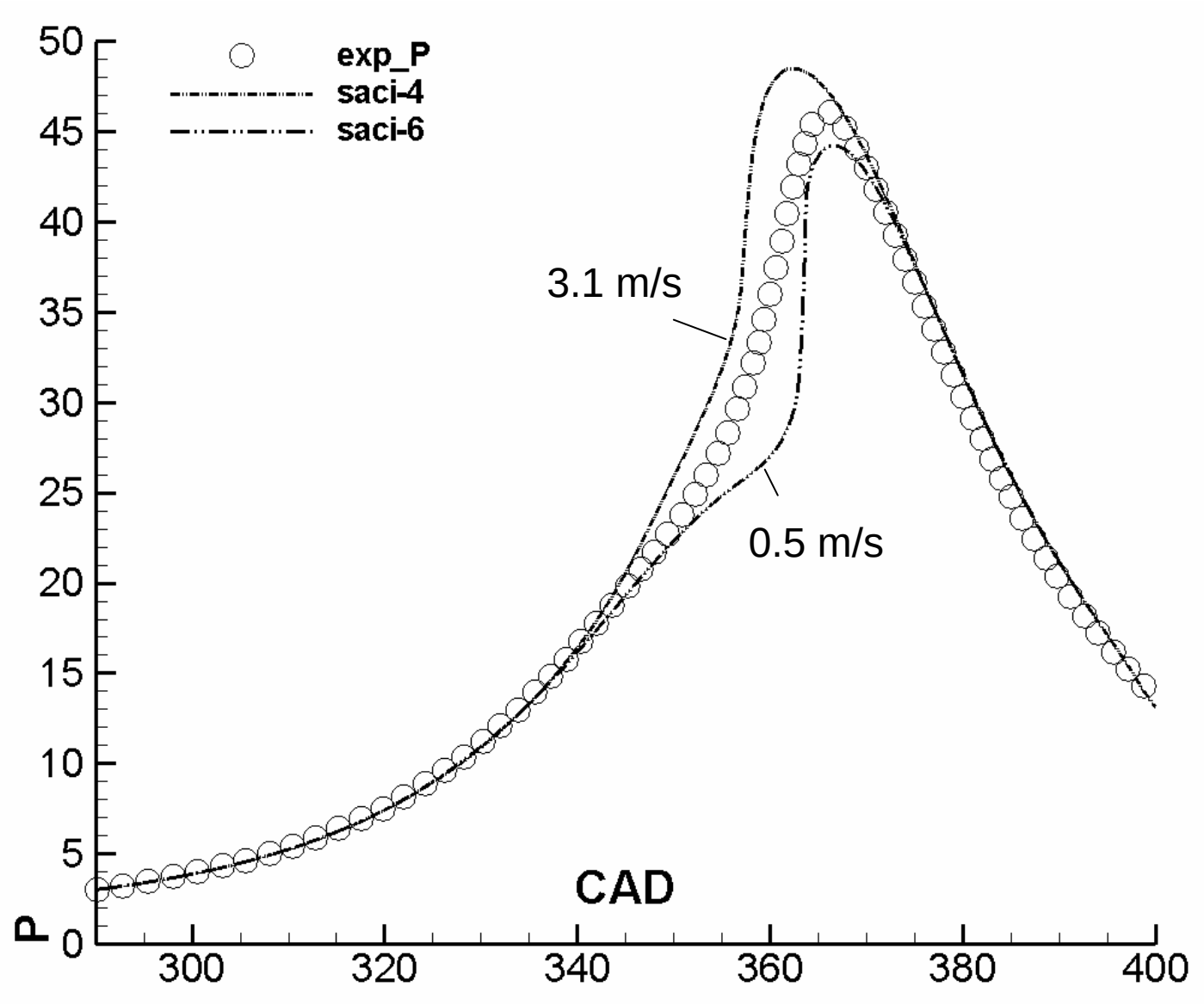
u’ = 3.1 m/s
T = 650 K
T’ = 20 K

saci-6: 2D temperature and incylinder pressure

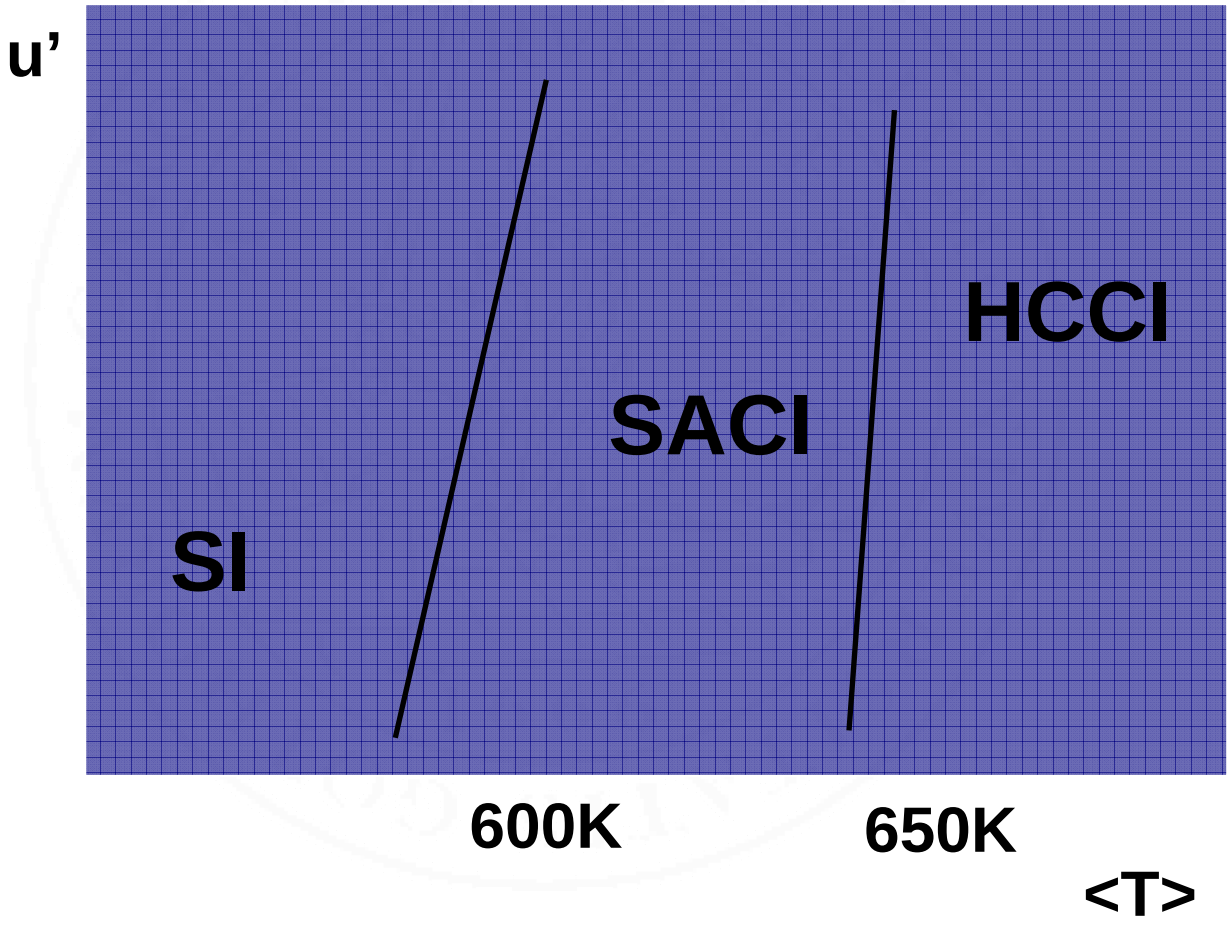


u’ = 0.5 m/s
T = 650 K
T’ = 20 K

Effect of u’ on the incylinder pressure



Effect of initial temperature and turbulence



Conclusions

- Initial mean in-cylinder temperature, temperature variance, and turbulence conditions are found to be important for the operation range of SACI

- At low mean in-cylinder temperature conditions,
  - SACI is in the SI mode, the charge rarely auto-ignited anywhere

- At high mean in-cylinder temperature conditions,
  - SACI is close to HCCI mode, since most of the charge are combusted by auto-ignition

- At moderate mean in-cylinder temperature conditions,
  - both SI and auto-ignition play important role, SACI is effective

- Increasing turbulence enhances the SI mode

Thank you
for your attention