TU/e technische universiteit eindhoven

Control Systems
Dept. of Electrical Engineering

Detection of Bifurcation in flow patterns in Glass Manufacturing Process

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PROMATCH

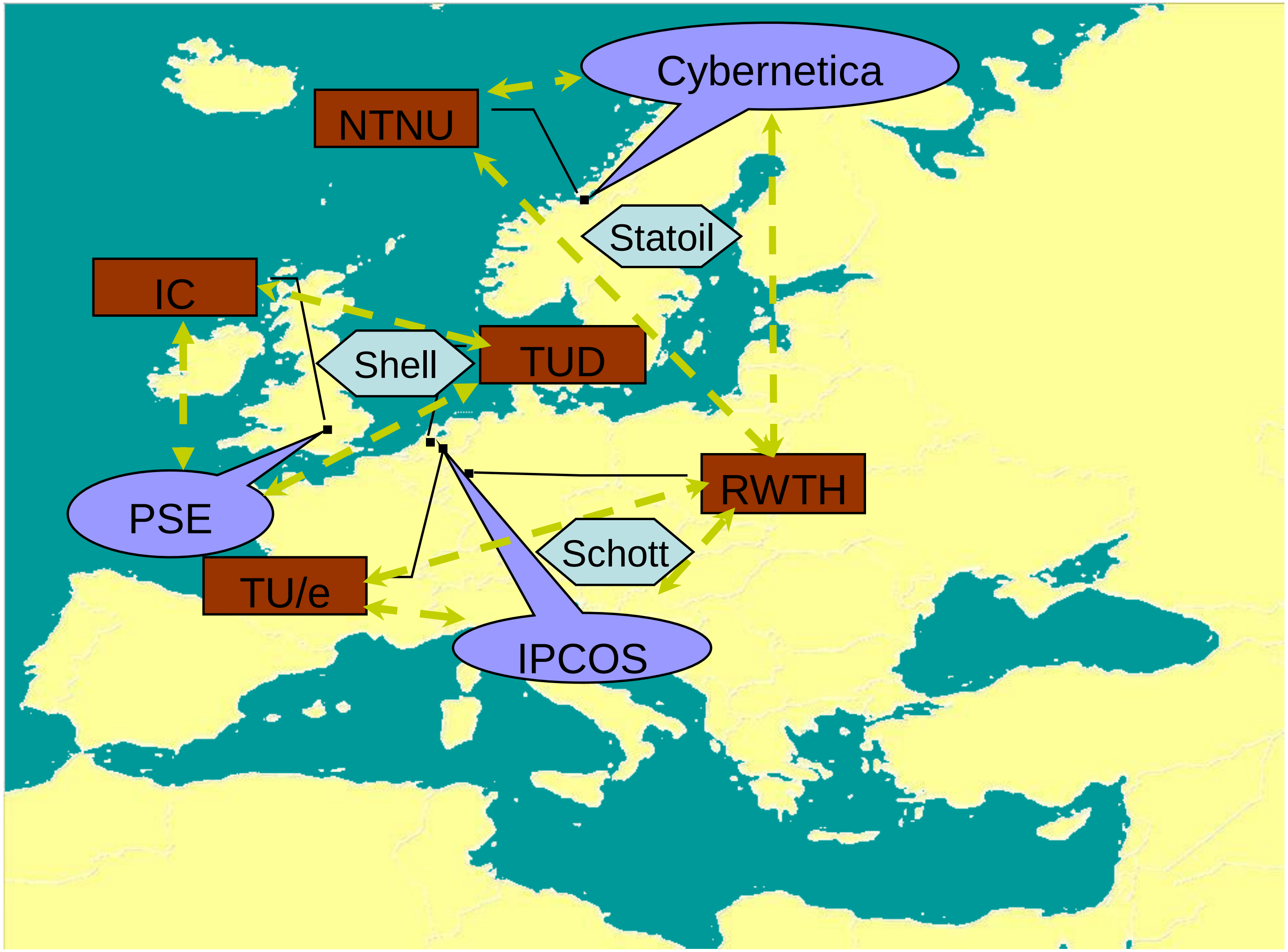
Marie Curie Actions
Human resources and mobility

Outline

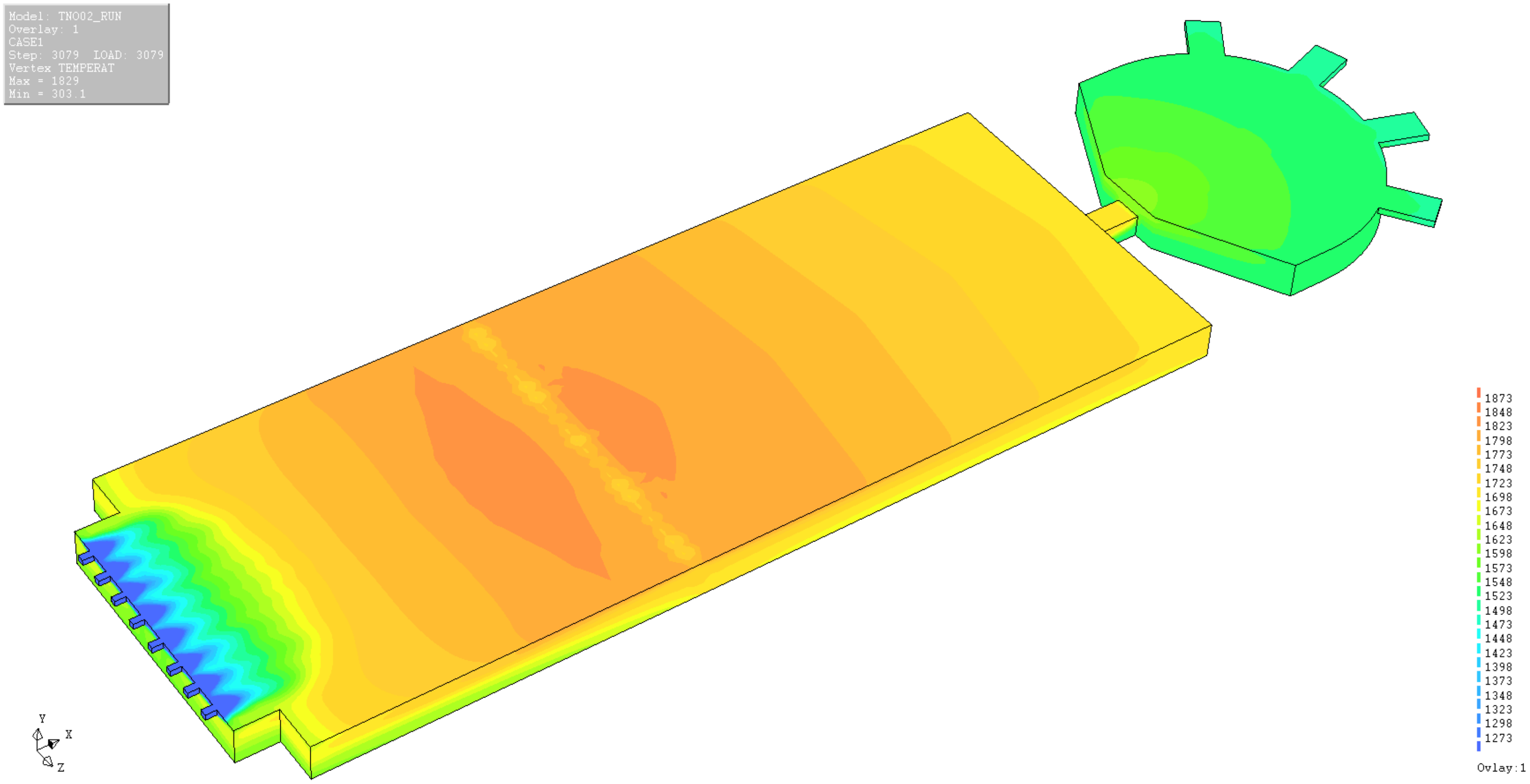
- Motivation – Glass + Corrosion
- Corrosion influence
- Problem statement
- Proposed solution- Detection mechanism
- Strategy towards solution of the problem
- Identification results
- Conclusion
- Benchmark problem repository

PROMATCH

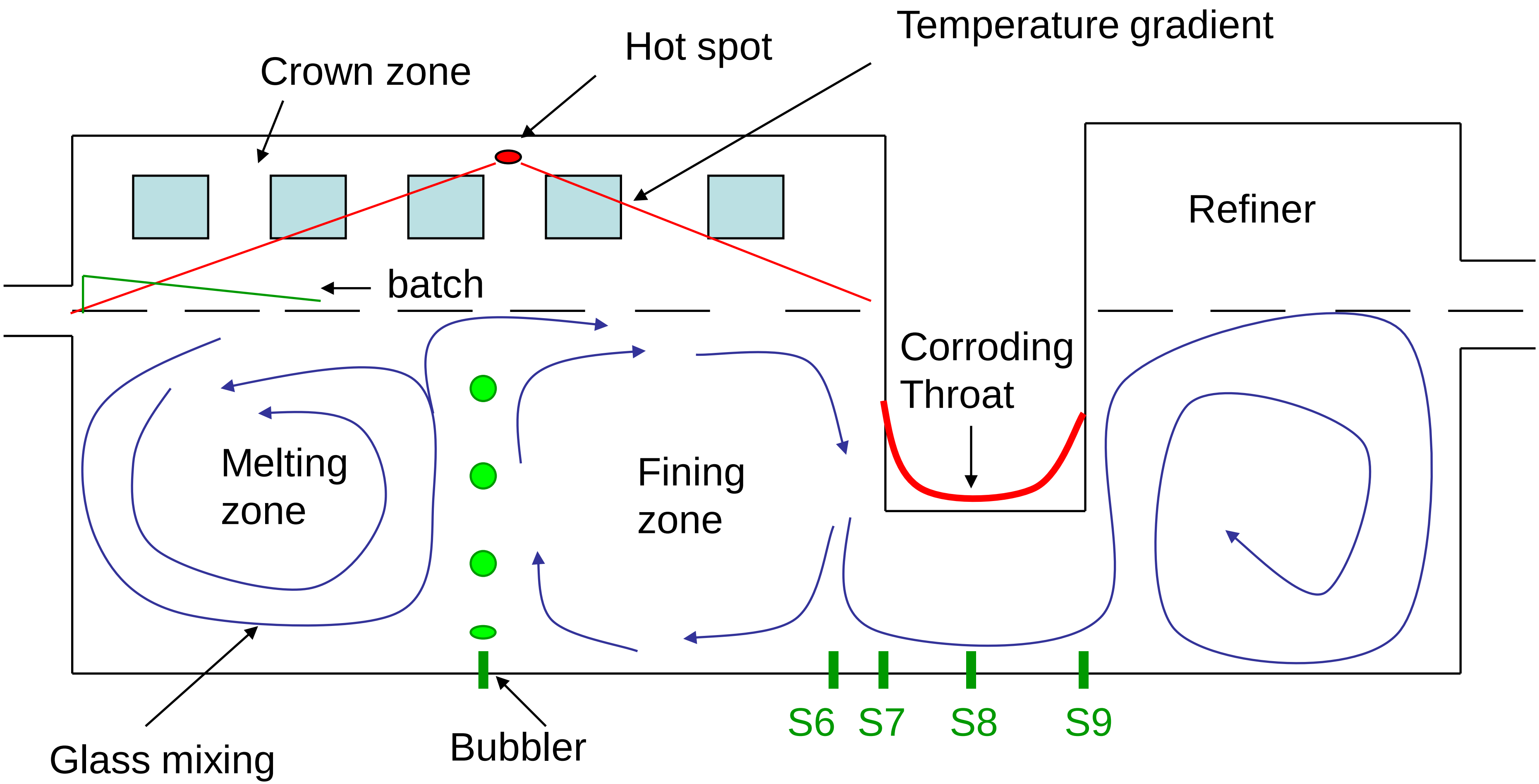
PROmoting and structuring Multidisciplinary Academic-industrial collaboration in research and Training trough SME teCHnology developers



Application: CRT Glass Manufacturing Tank



Motivation: Glass + Corrosion



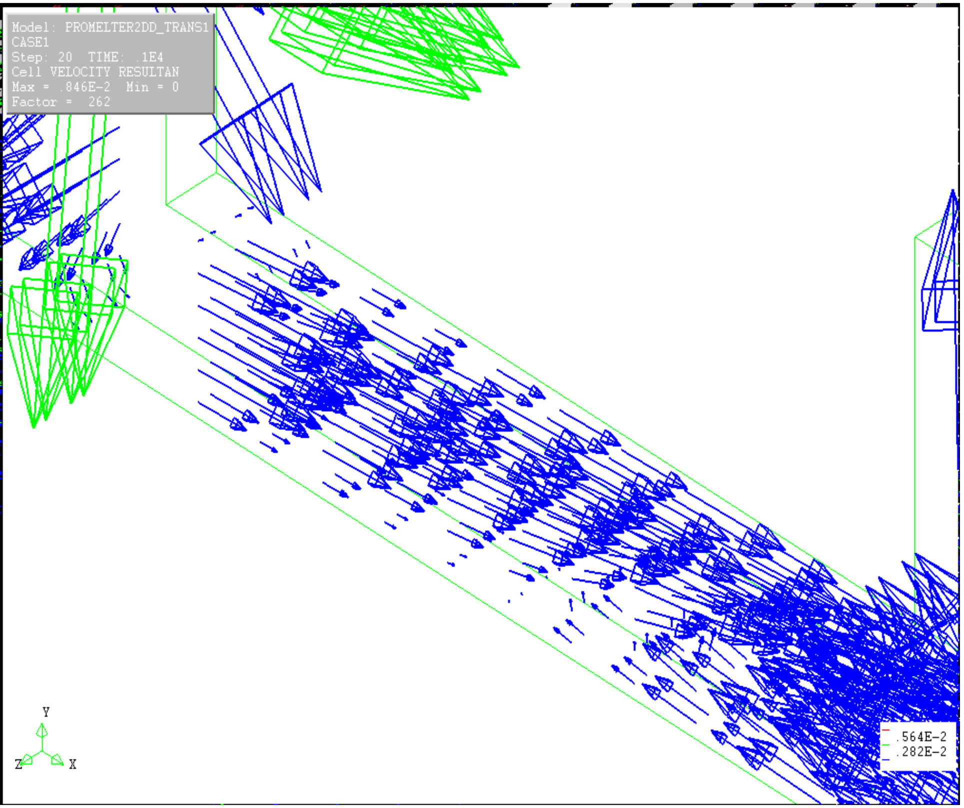
2D glass tank model Specifications

- Dimensions (m): 37.2 x 1 x 0.1
- 2 grid cells in z-direction, total ~ 6000 cells
- Capacity: 3.5 tons/day
- One bubbler
- Steep temperature profile in z-direction to get mixing in z-direction
- Almost complete model geometry parameterized
- Inclusion of basic models – flow, energy, batch, bubbling
- Model constants, parameter values, solver schemes, convergence criterion similar to 3D model

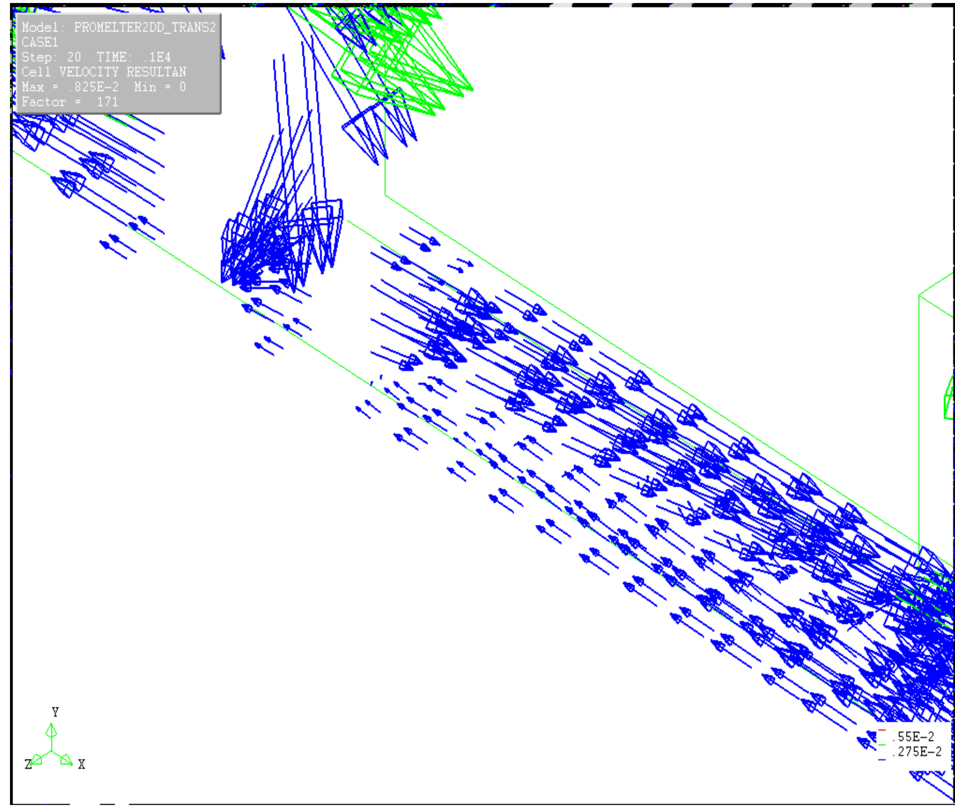
Outline

- Problem Description: Motivation
- Corrosion Influence

Occurrence of back-flow



Below critical value (h^-)

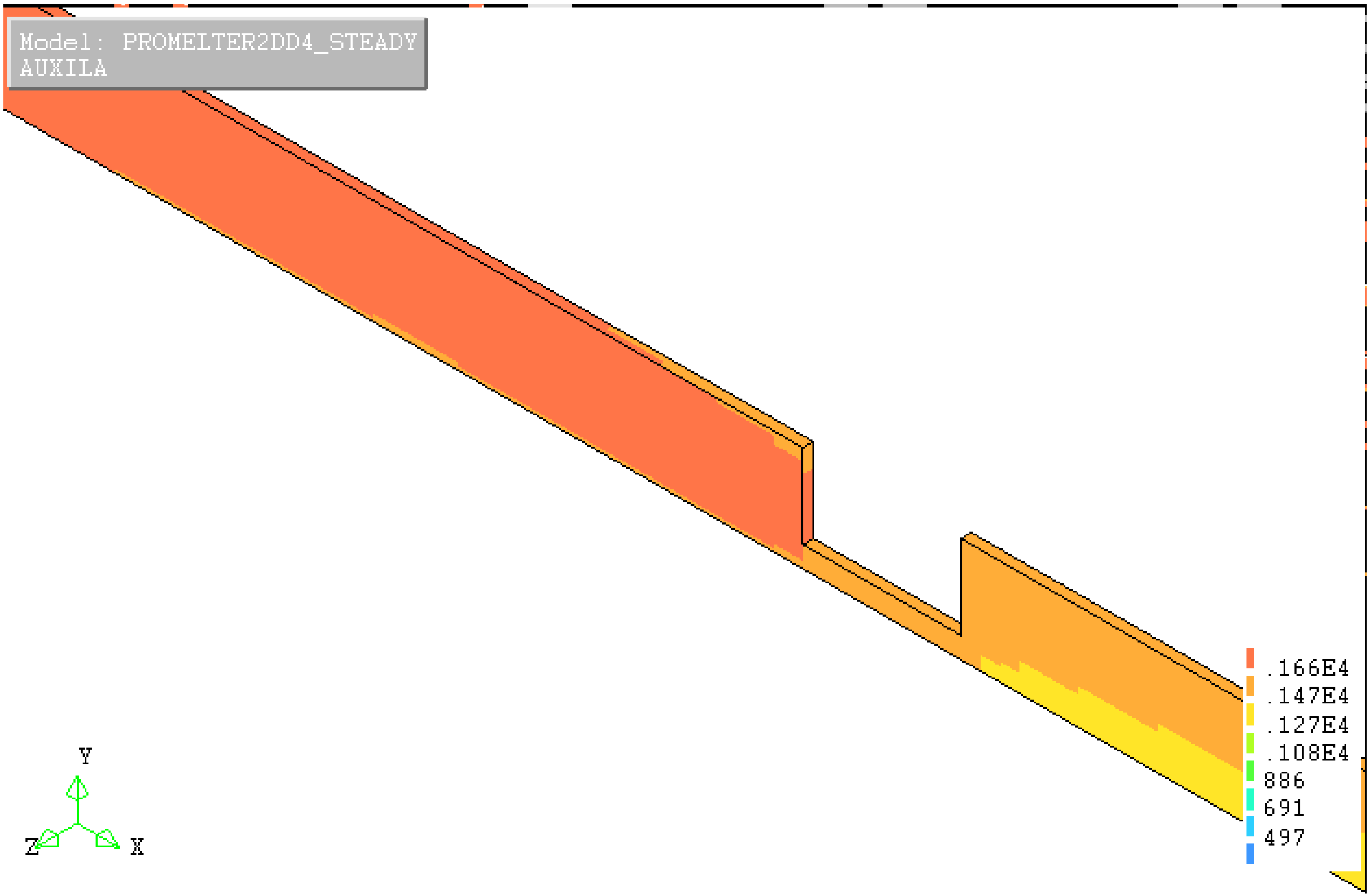


Above critical value (h^+)

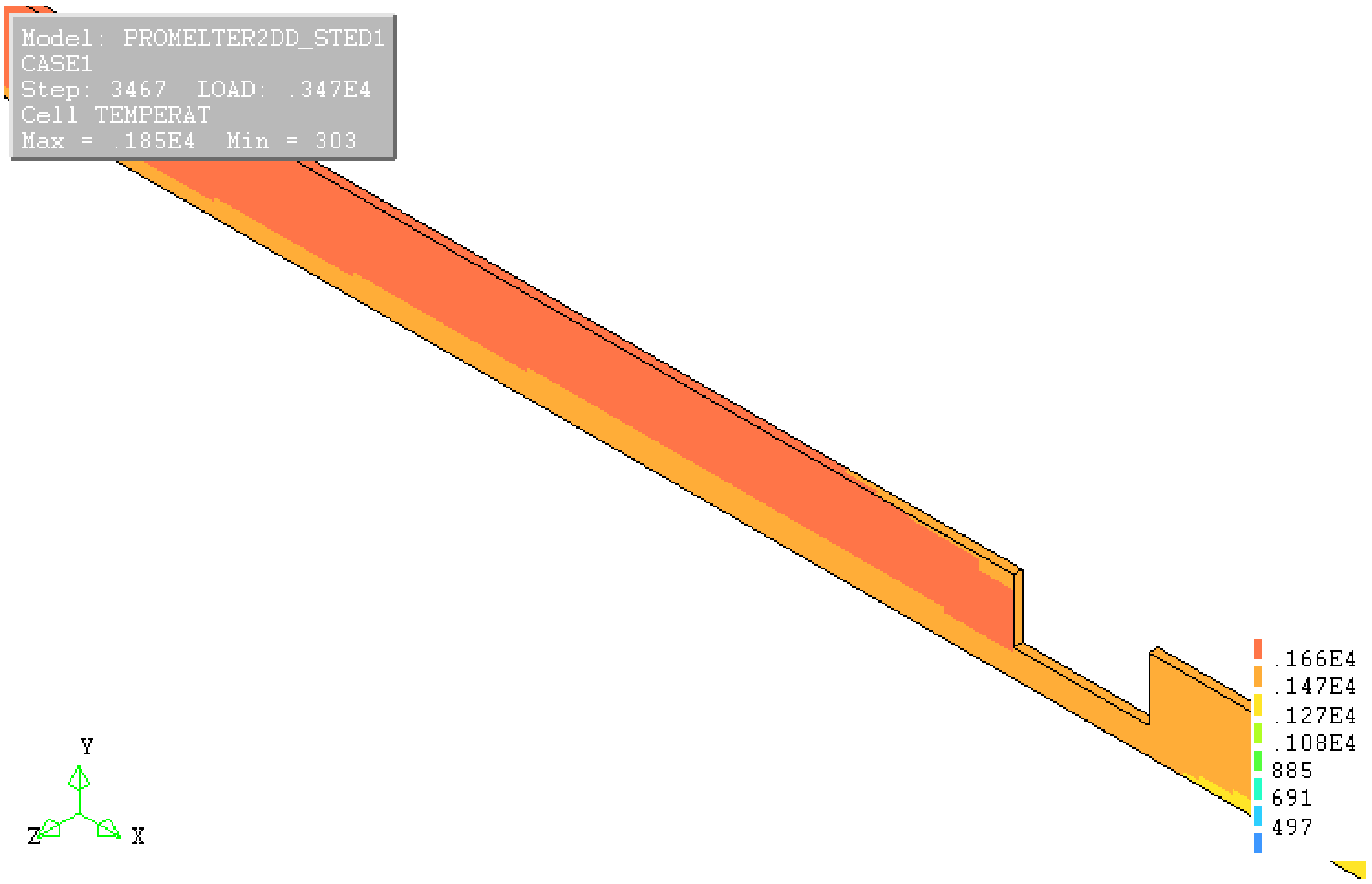
Bifurcation parameter window

$h^- < h^* < h^+ = 0.2\text{m} < h^* < 0.3\text{ m}$

Temperature (h=0.2)



Temperature (h=0.3)



Outline

- Motivation
- GTM-X experimental results
- Problem statement

Problem statement

For any of the following systems-

$$\sum\nolimits_{h_1} : f \quad x, y, z, T, Velocity, \ldots h = h_1$$

$$\sum\nolimits_{h_2} : f \quad x, y, z, T, Velocity, \ldots h = h_2$$

$$\sum\nolimits_{h_3} : f \quad x, y, z, T, Velocity, \ldots h = h_3$$

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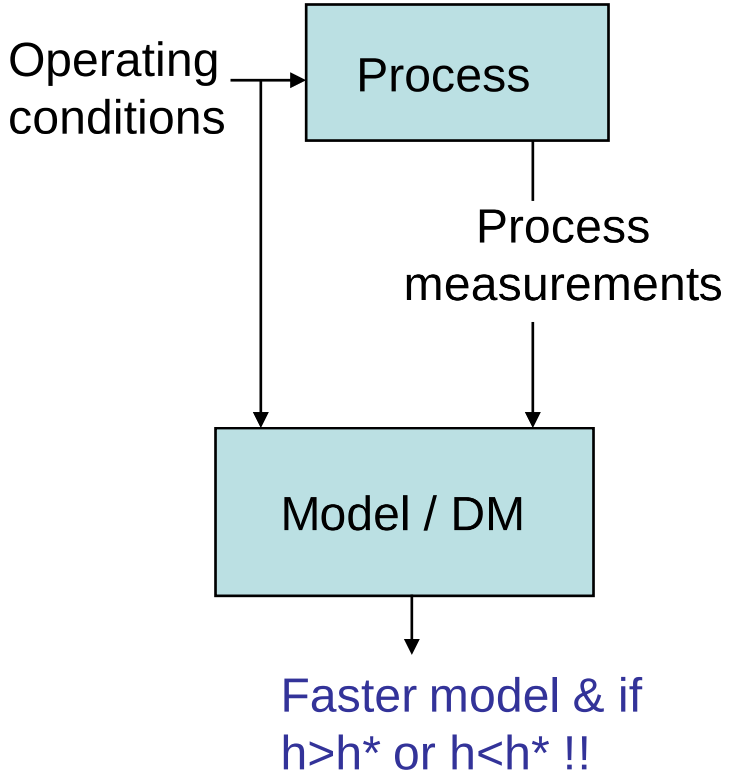
$$\sum\nolimits_{h_n} : f \quad x, y, z, T, Velocity, \ldots h = h_n$$



Q: Given few measurements and some system knowledge, can one detect the bifurcation parameter value?

A: POD + subspace identification + Dynamic Detection Mechanism

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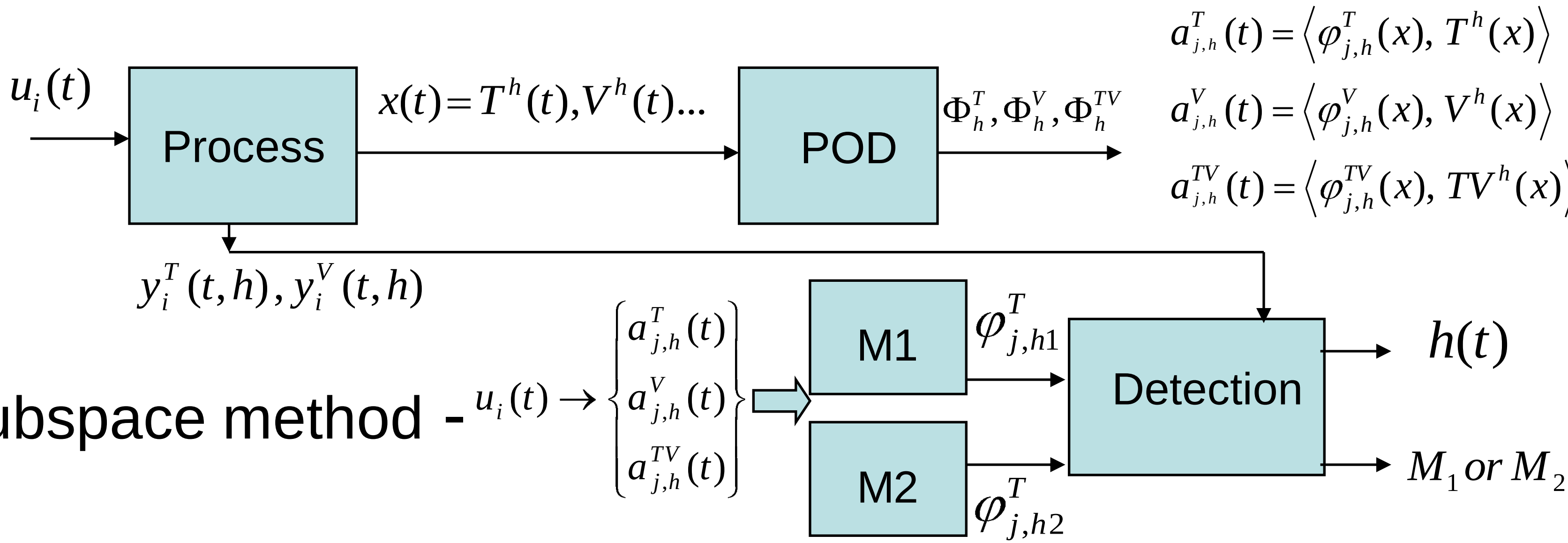
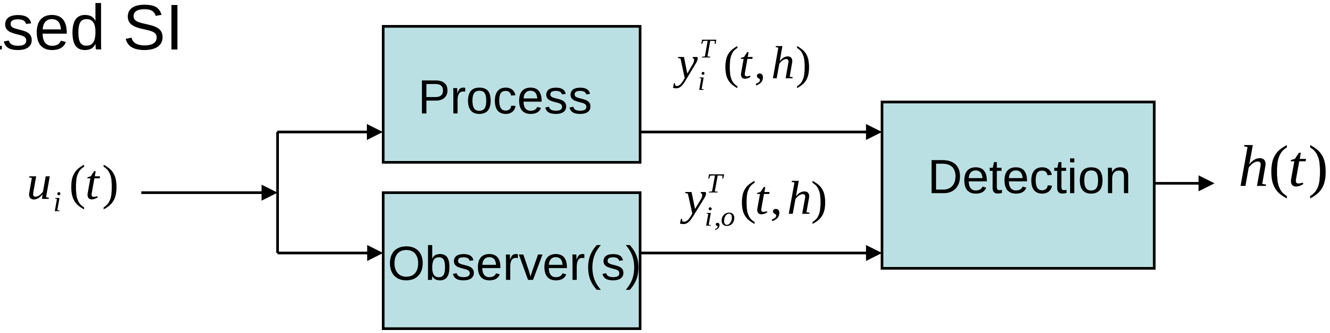
Strategy towards solution of the problem

- POD based (for h_1=0.2, h_2=0.3)



SI: Subspace method -

- Observer Based SI



Proper Orthogonal Decomposition (POD)

- POD Basis Problem

Given data $w_1,...w_M \in W,$ find orthonormal basis $\{\varphi_k, k=1,2,...\}$ of W such that the error

$$J(\varphi_1,...\varphi_r) = \sum_{j=1}^{M} \| w_j - \sum_{k=1}^{r} \langle w_j, \varphi_k \rangle \varphi_k \|^2$$

Is minimal for all truncation levels r

Basis are-

1. Data dependent
2. Needs inner product $\langle f, g \rangle$ on W
3. Basis needs to be orthonormal

Solution to POD basis problem

- An orthonormal basis φ_k is POD basis if and only if
  $WW^T \varphi_k = \lambda_k \varphi_k$
- Problem of finding POD basis is equivalent to eigenvalue problem
- Need to compute , $W = U \Sigma V^T$ i.e. Singular Value Decomposition
- U,V : unitary matrices, ∑ singular values arranged in decreasing order, columns of U form POD basis
- Original DPS model is projected on POD basis, φ_k Galerkin projection when U=V

POD continued…

- PDE or distributed systems
- Model: $$\frac{\partial w}{\partial t} = F\left(w, \frac{\partial w}{\partial z}, \ldots, \frac{\partial^n w}{\partial z^n}, u \right)$$
- Variable projection
  W(x,t) ≈ **U** W_r(x,t)
- Vector field projection

$$imV \perp \left(\frac{\partial w}{\partial t} - F\left(\frac{\partial w}{\partial x}, \ldots u \right) \right)$$

- Galerkin Projection U=V

- Reduced order model
- Variable and vector field projections are combined
- Inner product on Hilbert space yields reduced models

$$\left\langle v, \frac{\partial w_r}{\partial t} \right\rangle = \left\langle v, F\left(w_r, \frac{\partial w_r}{\partial x}, \ldots, \frac{\partial^n w_r}{\partial x^n} u \right) \right\rangle$$

$$\boldsymbol{w_r} = \langle \boldsymbol{u}, \boldsymbol{w} \rangle$$

$$y(x,t) = g(w_{r,} u)$$

- Where $u \in imU, v \in imV \,\&\, \langle .,. \rangle$ is inner product

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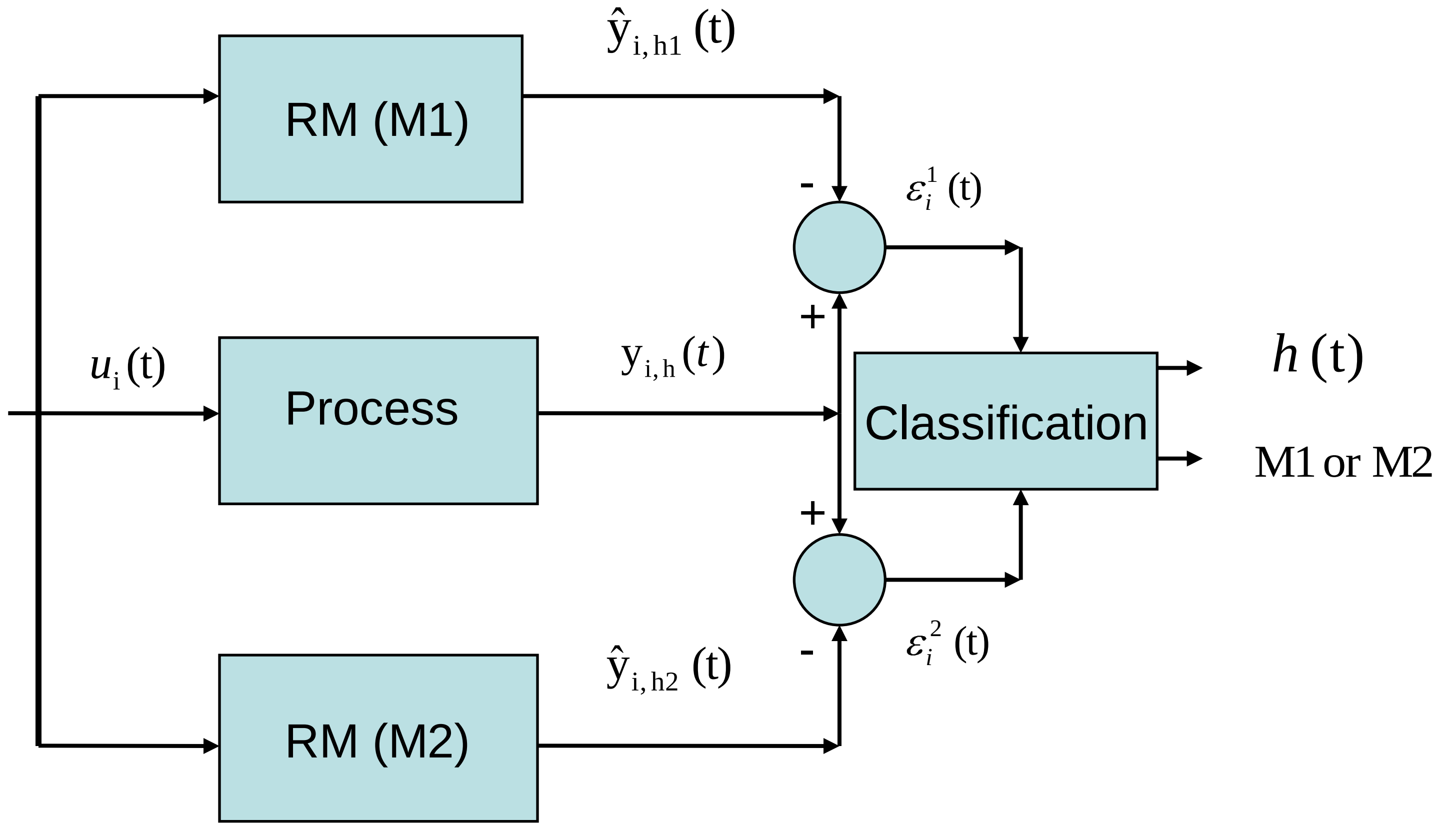
Bifurcation Detection



Assumption : Process bifurcation parameter is above or below critical value.

Disadvantage: For small difference and substantial noise presence can lead to wrong result.

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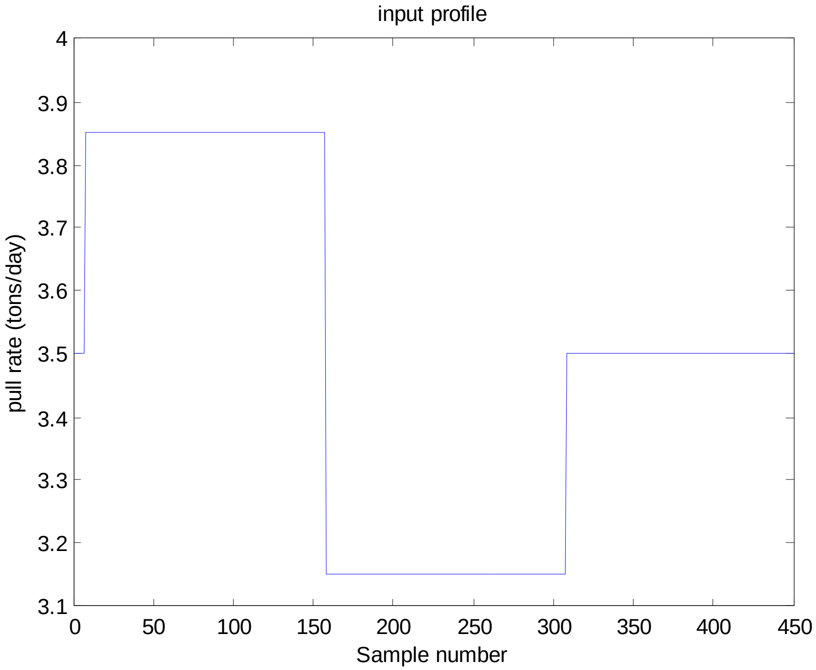
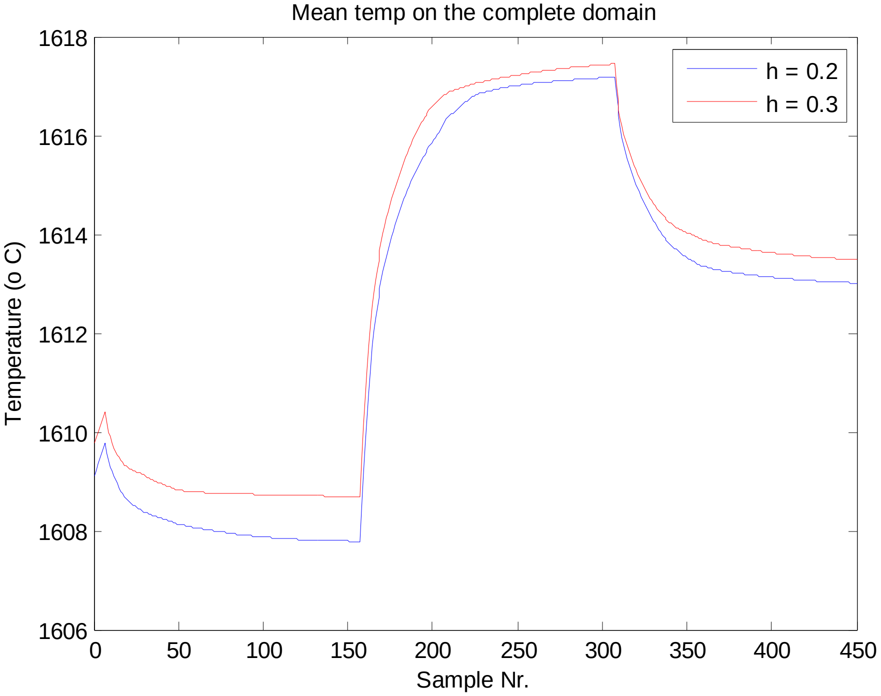
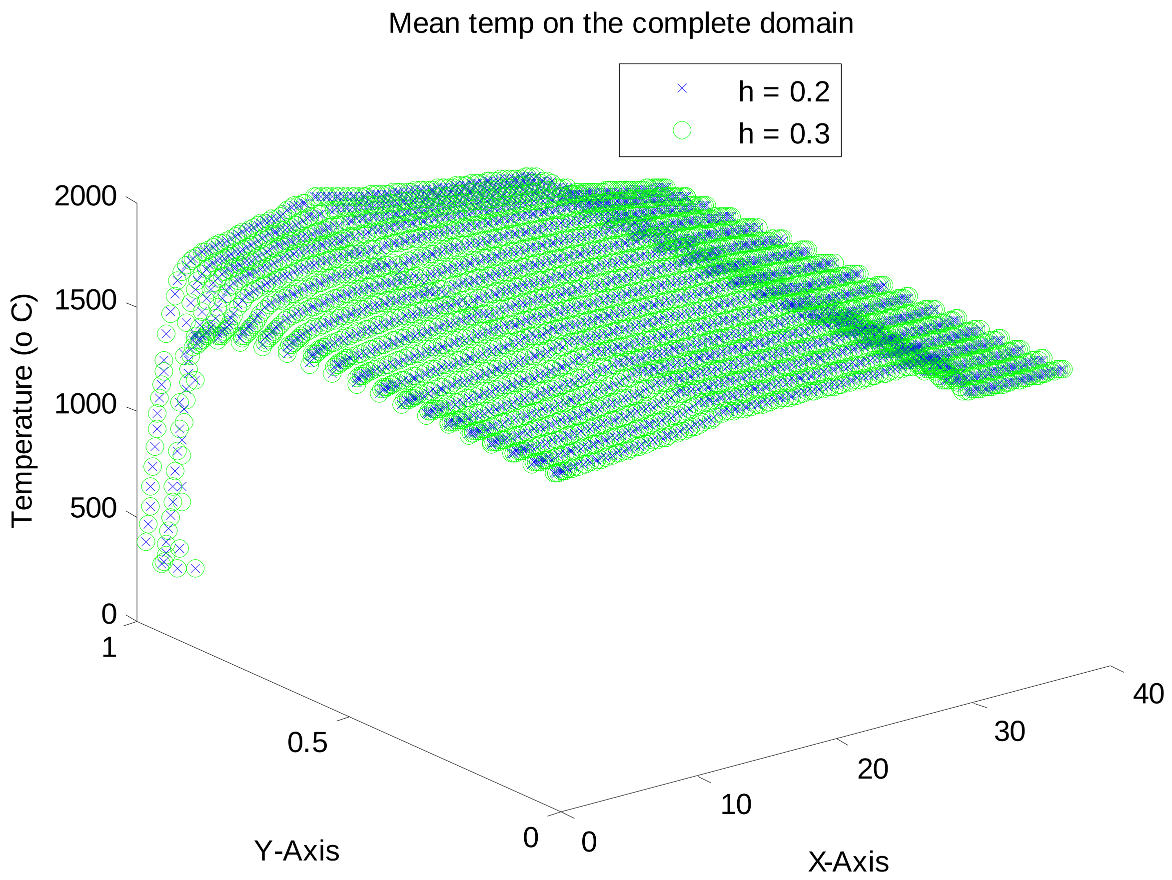
Average Temperature Profile in the tank – mean on domain, actual data

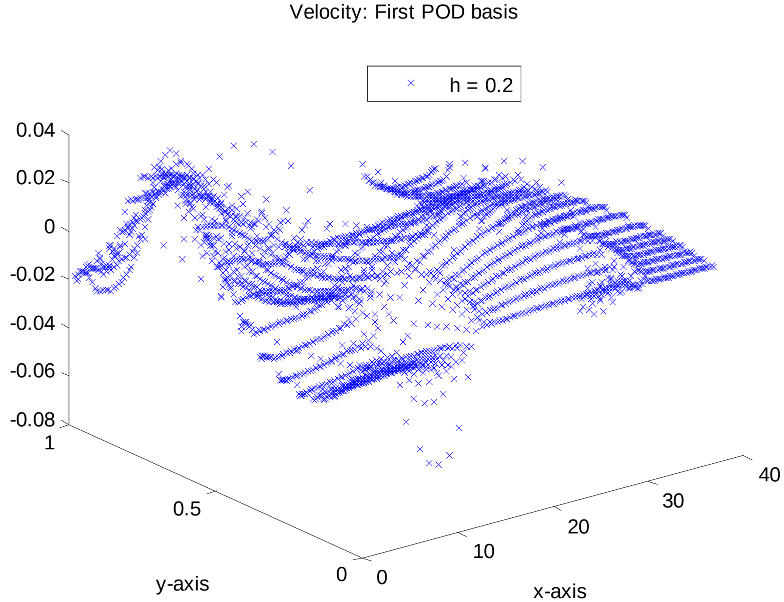


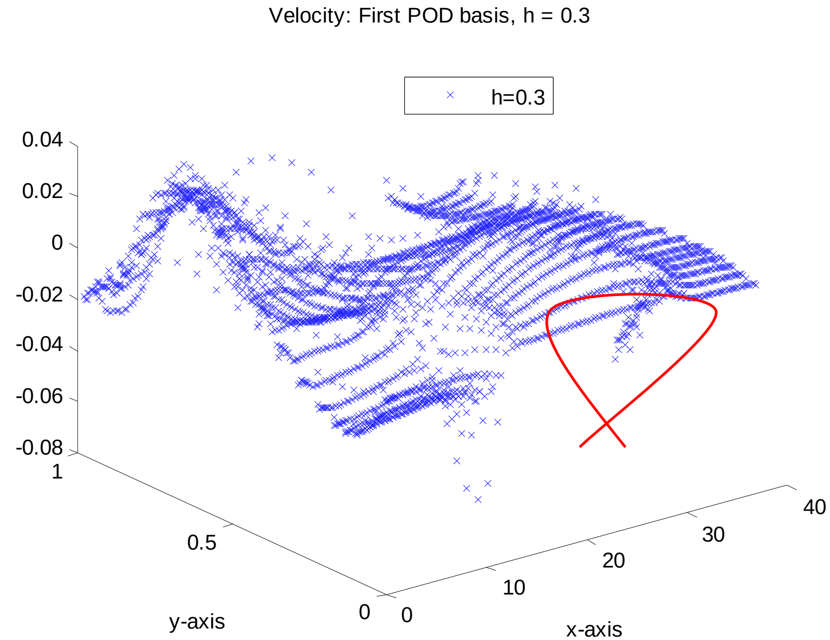


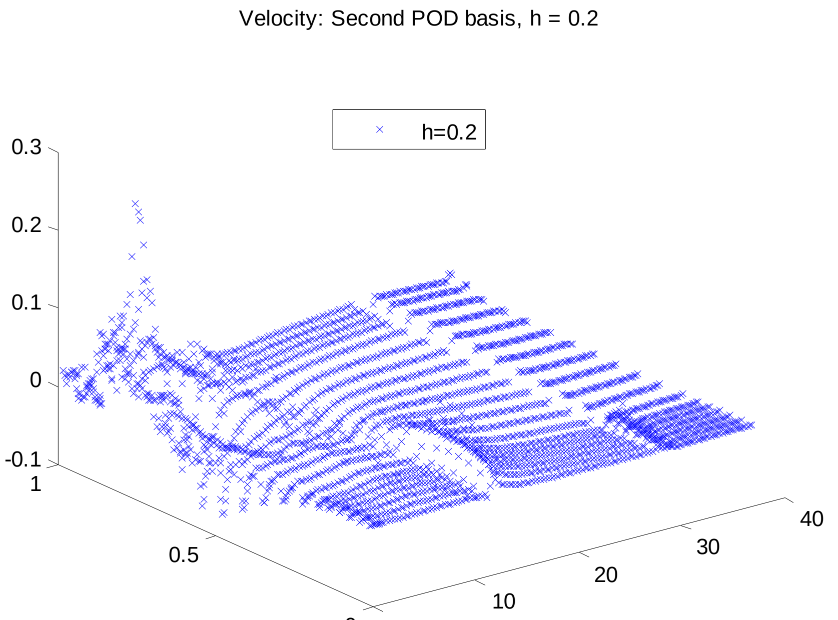
Average Temperature Profile in the tank – mean on time

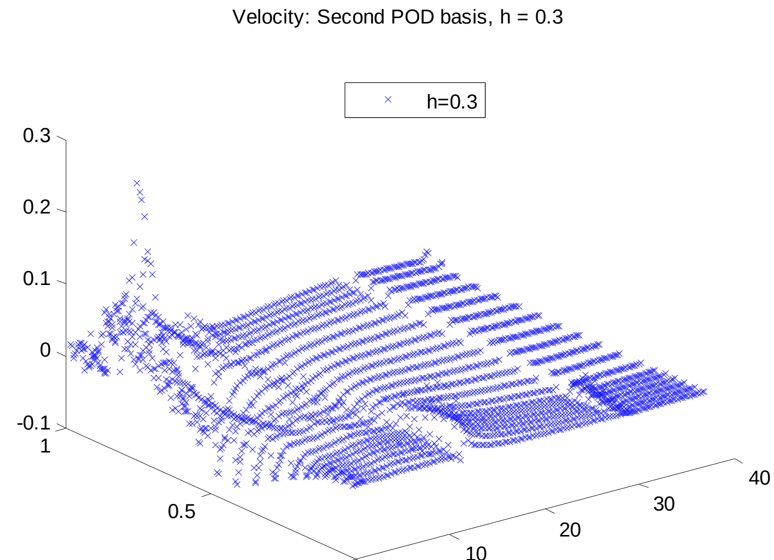


First four POD basis functions (V), h=0.2, 0.3

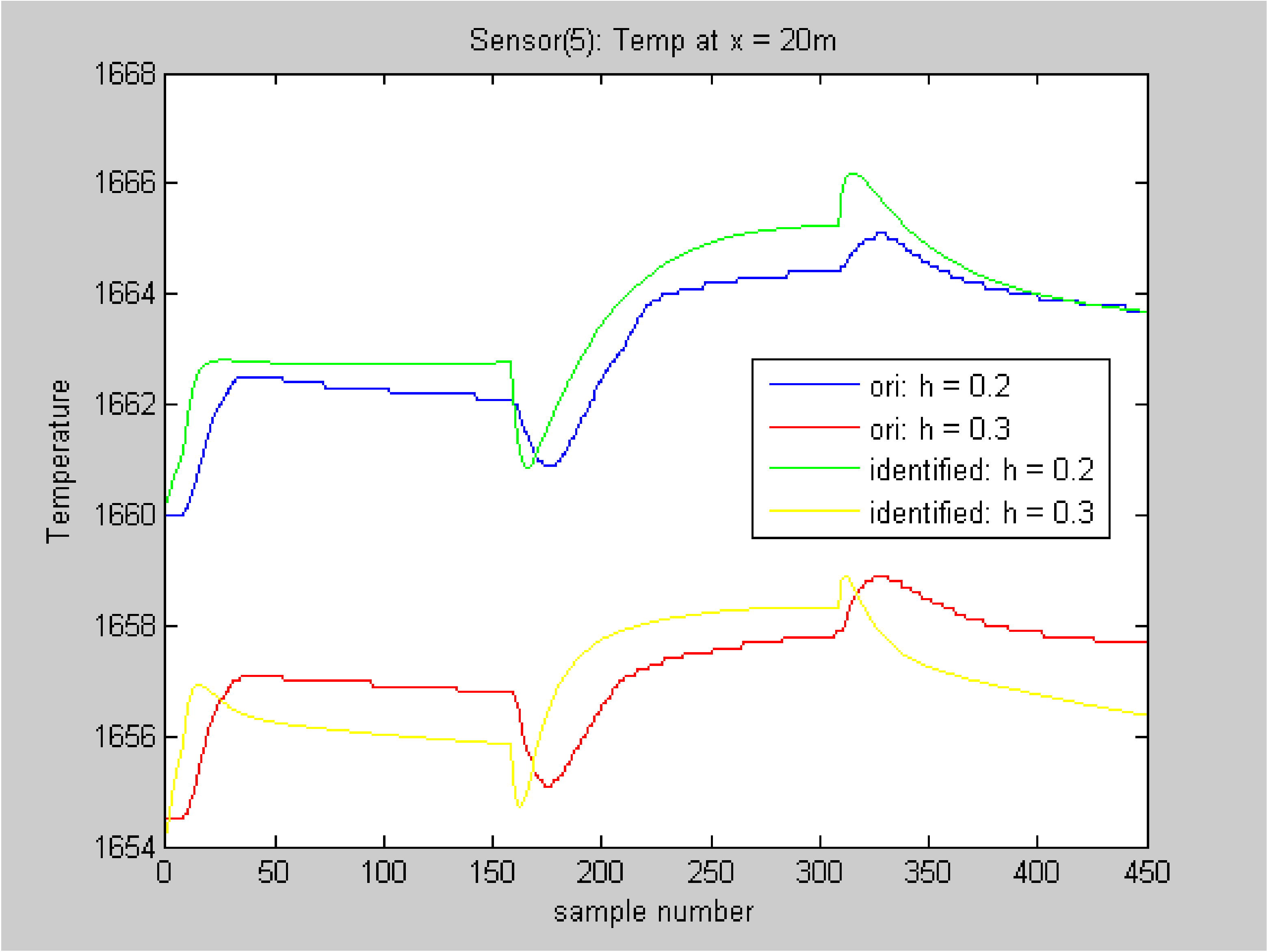




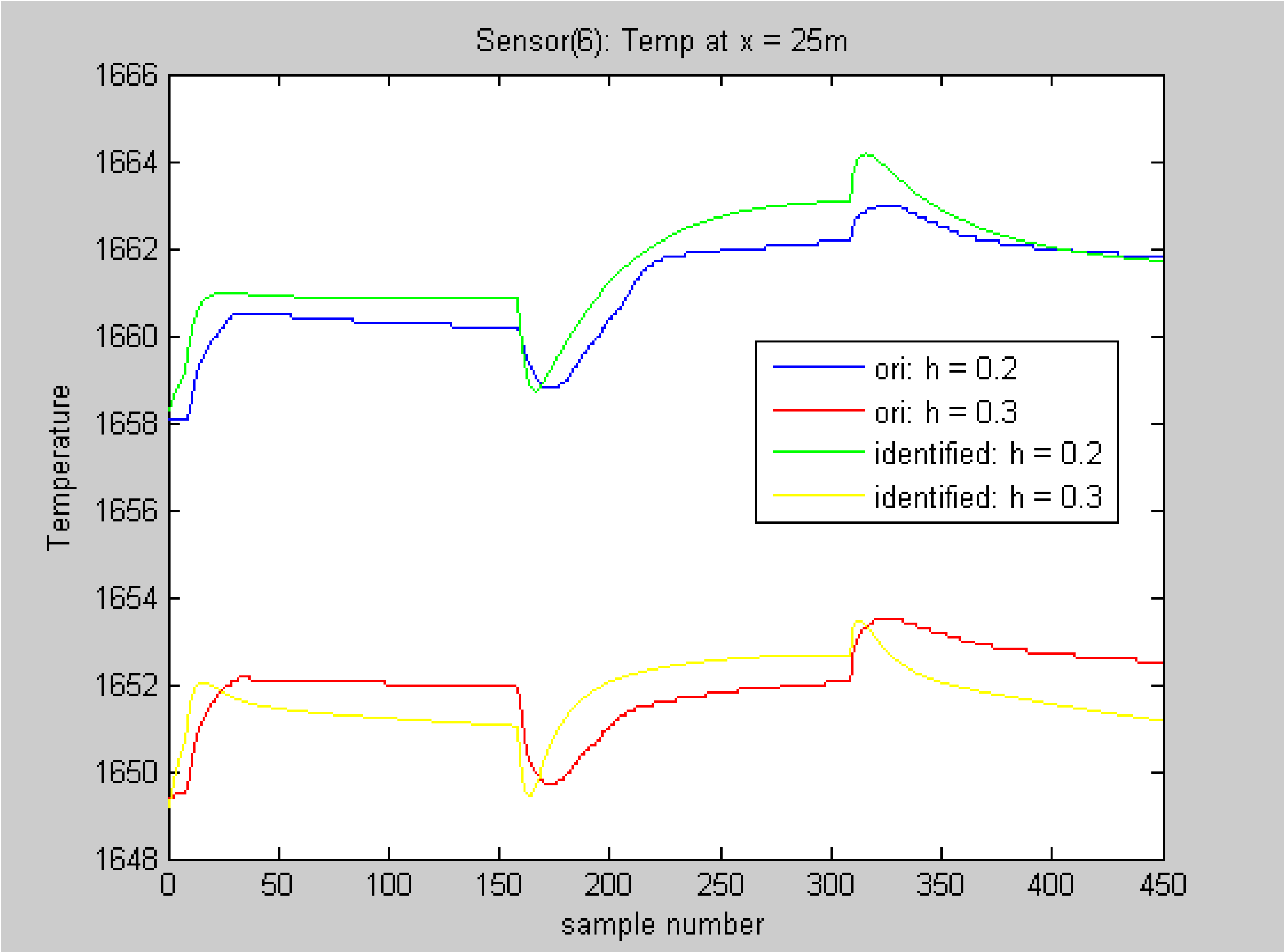




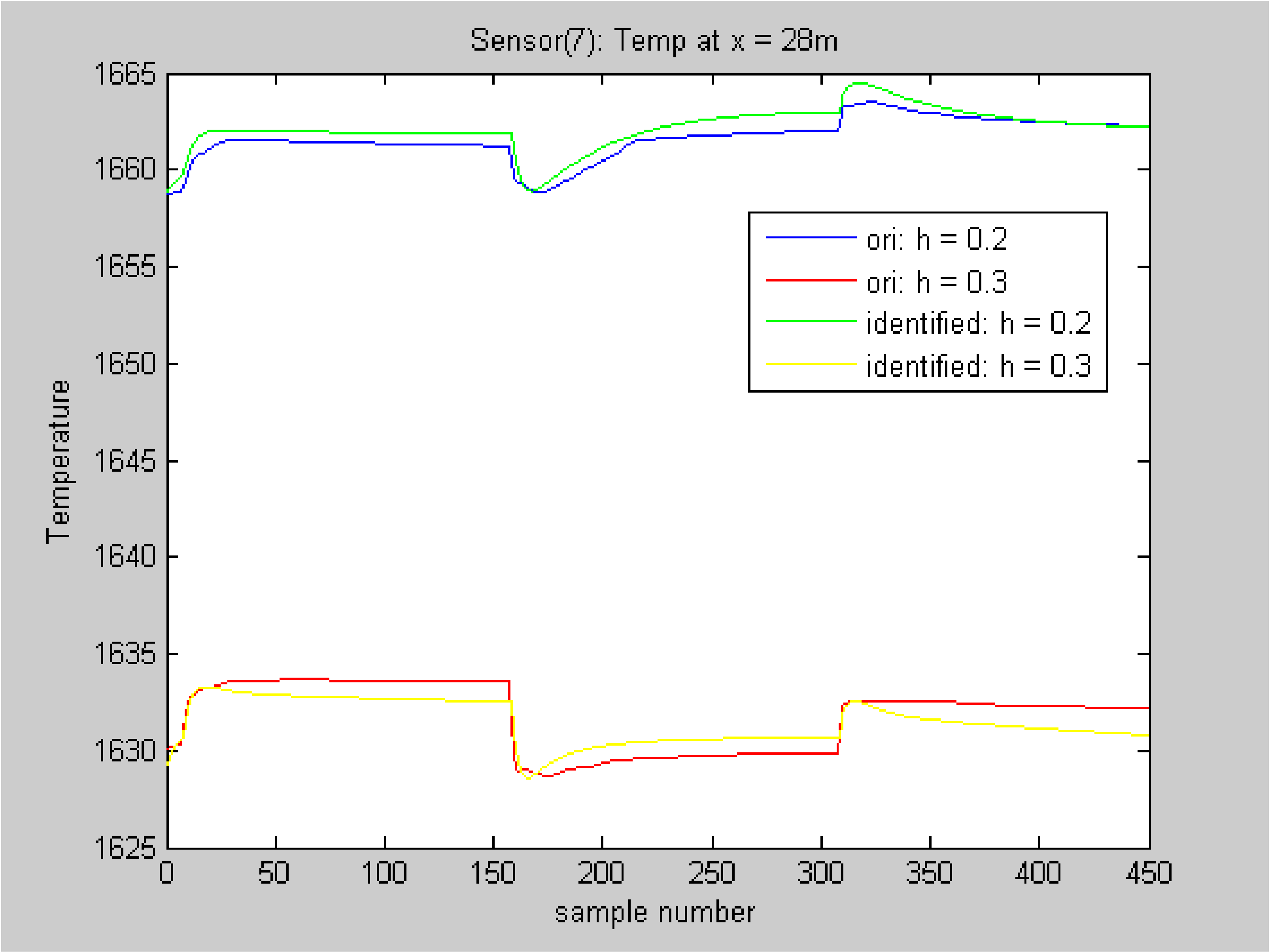
Temp, x=20m (7m left side of throat)



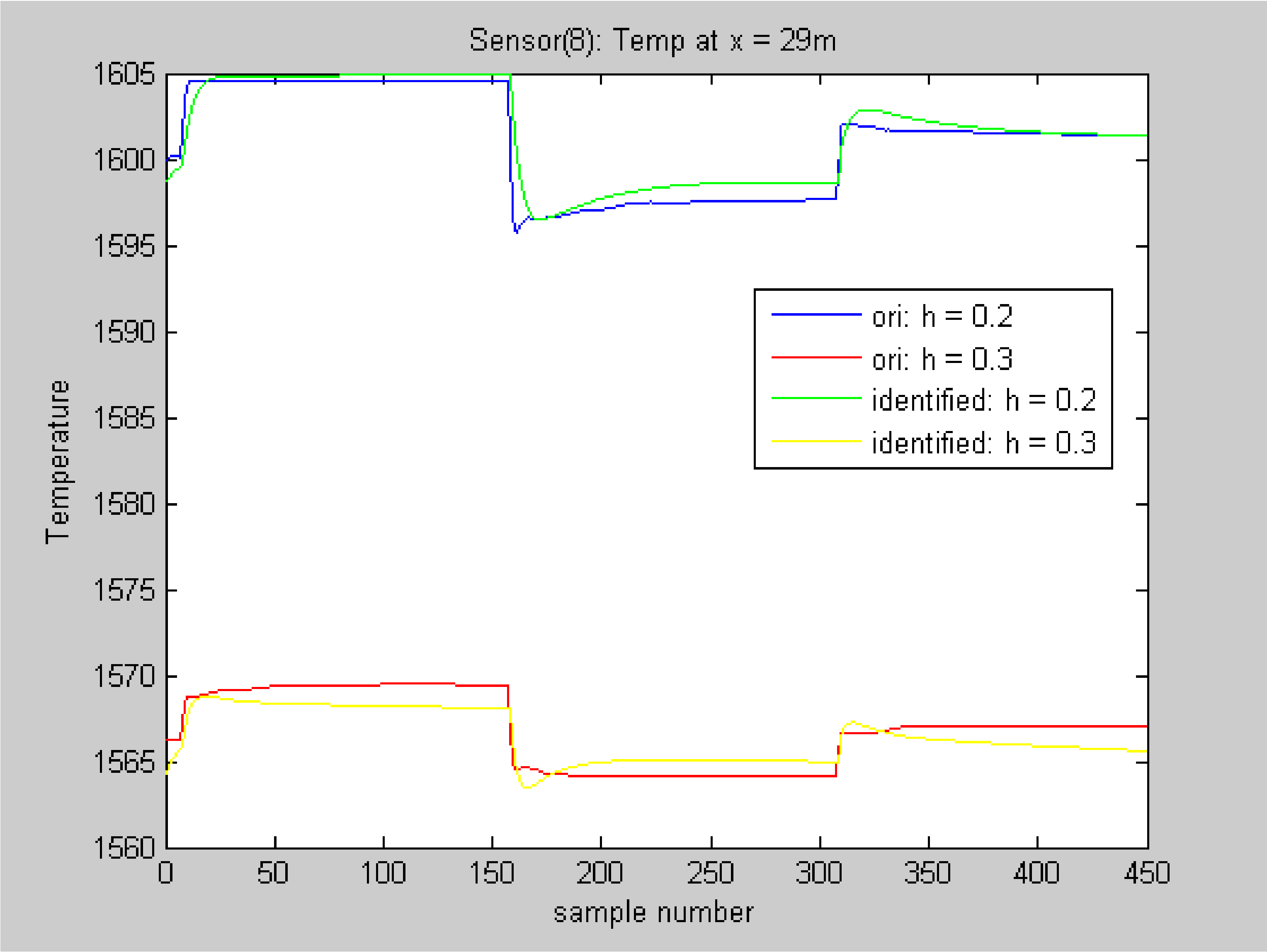
Temp, x=25m (3m left side of throat)



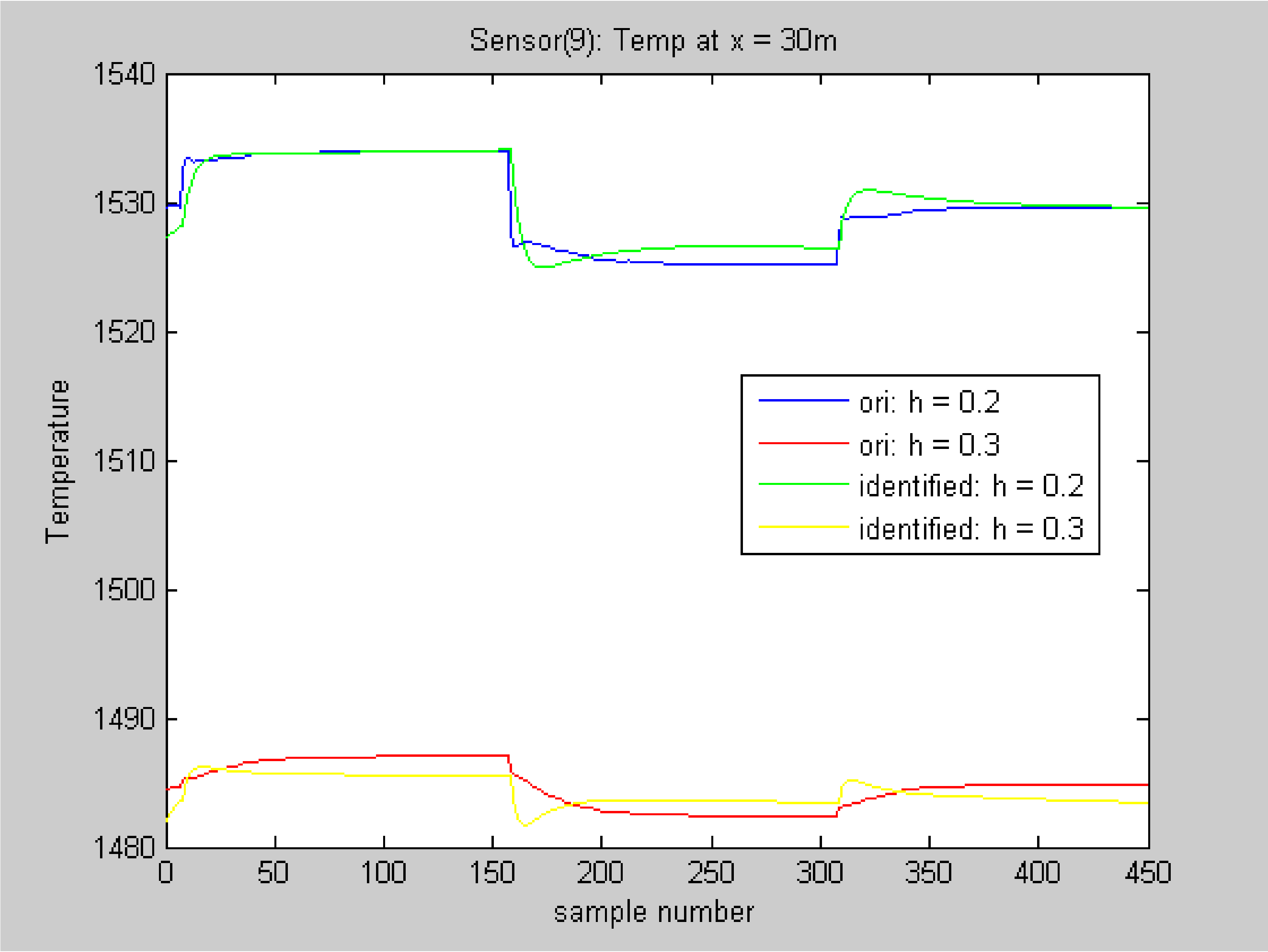
Temp, x=28m (start of throat)



Temp, x=29m (middle of throat)



Temp, x=30m (end of throat)



Conclusions and future work

- Detection mechanism based on reduced model identification (subspace) can probably be used for detecting corrosion occurring in the glass manufacturing process.

- Effectiveness of this approach need to be checked for smaller corrosion effect.

- Closed loop performance (to stop back-flow)

- Observer based detection mechanism

- Distinguishability based on POD basis

References

- P. Astrid, PhD report 2004
- L. Huisman, PhD report 2005
- Wattamwar S., Weiland S., CCA 2008 contribution

PROMATCH Symposium

- On November 4 – Frankfurt, DECHEMA
- Will have presentation from invited speakers and PROMATCH partners
- Benchmark problem repository + methodology documentation, will be distributed (CD)

Benchmark Repository – Process Industry

- Systems – Lumped, Distributed, Mixed
- Applications – Glass, Distillation, CSTR
- Methodologies – POD+SID, Grey-box model, Compartmental model, Hammerstein model
- Platforms – Matlab, GTMx, Gproms, etc.
- Level – easy to Complex
- Problems – software licenses!!

PROPOSAL to this group

- Share the presentation slides !!

THANK YOU!!