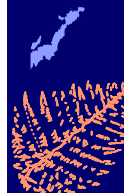


Introduction to
History Matching
Workshop

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OUTLINE

- *What is History Matching*
 - *Yes, but what is it really?*
 - *What is it not*
 - *Prerequisites*
 - *What's the point*
 - *What can we achieve*
 - ▶ *Realistic expectations?*
- *Examples from related disciplines*
- *Examples from petroleum industry*
- *Automatic History Matching?*

REAL HISTORY MATCHING



Original photograph



Official photograph after
Trotskij had fallen into disgrace

Now you see him -- now you don't

BACKGROUND

- *"Everything" can be described by mathematical models*
- *System of (differential) equations:*
 - *Logic deduction based*
 - *E.g. Conservation laws*
 - *Empirically based*
 - *E.g. Newton's laws of motion, Kepler's laws of planetary motion, Darcy's law*
 - *"Spectacular" assumptions*
 - *E.g. Darcy's law for multiphase flow*
- *Initial Conditions (I.C.)*
- *Boundary Conditions (B.C.)*

BACKGROUND (2)

- *The mathematical / physical model*
 - *How good is it?*
 - *E.g. Newton's laws vs. Theory of Relativity*
 - *Can it be solved?*
 - *How well known are the input data?*
 - *Coefficients, I.C., B.C.*
- *Exact analytical solutions are almost never possible*
 - *Approximations to the model*
 - *Approximative solution methods*
 - *Approximations to input data*
- *Numerical solution methods*
 - *Linearisation*
 - *Approximate coefficient matrix inversion*
 - *Numerical accuracy*
- *There are lots of error sources!*

EXAMPLE 1: AIRCRAFT INDUSTRY

- *P.D.E. system is well known*
- *B.C.s are well known*
 - *Aircraft shape*
 - *a priori "unknown", but exactly described for each case study*
 - *point is to optimise shape w.r. to total air resistance*
- *Solution method based on*
 - *approximation of model*
 - *numerical approximation techniques*
- *In recent years, the numerical solutions are judged as sufficiently good that prototype construction and wind tunnel experiments have been eliminated*
- *"Proves" that the approximation rules we use are good enough provided the model and input data are of sufficiently high quality.*

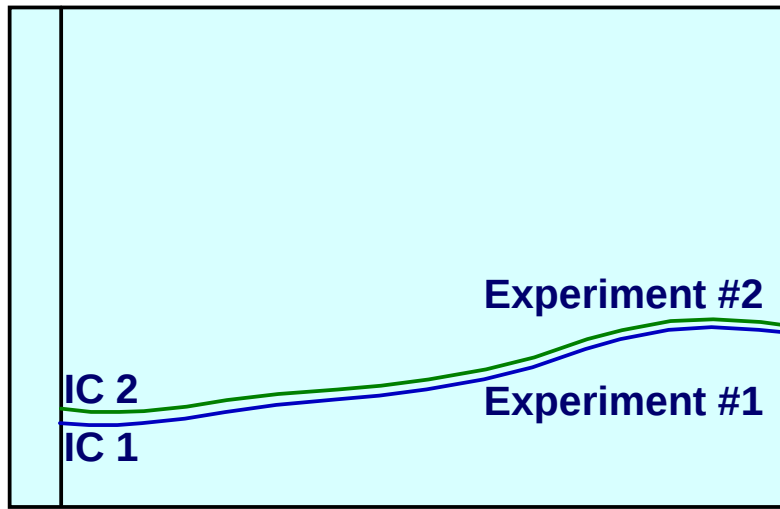
EXAMPLE 2: METEOROLOGY

- *P.D.E. system is well known*
- *B.C.s are well known (ground topography)*
 - *Coarse approximations necessary*
- *I.C. known, but not always accurately enough*
 - *"Present" weather condition*
- *Solution method based on*
 - *approximation of model*
 - *numerical approximation techniques*
- *Solution method good enough, but model is **unstable**.*
- *We all know how reliable weather forecasts are*
 - *However, on e.g. U.S. Midwest Plains / at sea, the forecasts are extremely detailed and accurate*
 - *Smoother topography implies the B.C.s are more accurate.*

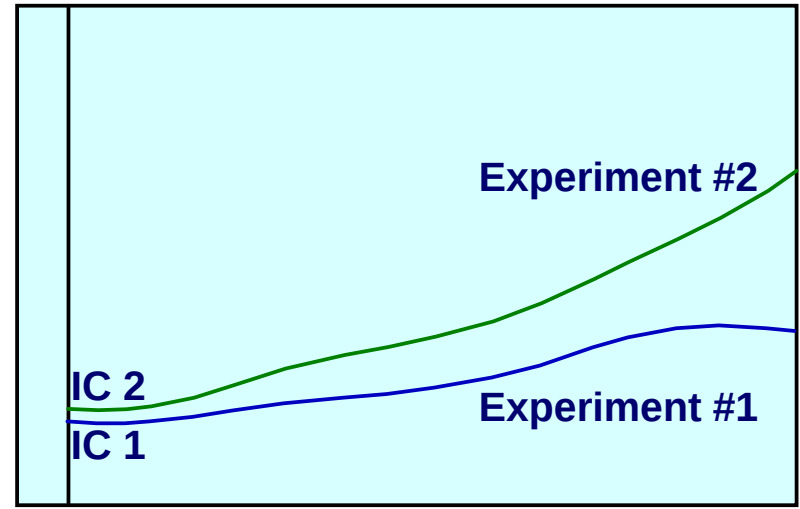
STABILITY

- *In physical experiments we intuitively expect that experiments performed under "almost identical" conditions will have "almost identical" results.*

Stable solution



Unstable solution



"HISTORY MATCHING" IN METEOROLOGY

- *A data base consisting of ~100 years of weather history was constructed*
 - *Idea / hope was that "history repeats itself"*
 - *By comparing e.g. weather last 5 days with each 5-day period in the data base and finding the best match one could assume that the weather the following days could also be read out of the historical data.*
 - *Would replace the computing of predicted weather (which is a rather CPU demanding process)*
- *Complete disaster.*
- *Again a result of the unstable solution: Even a tiny difference in I.C. will grow "beyond all bounds" with time.*



THE GREAT DIFFERENCE

- **Standard procedure:**
 - From system of equations $L(\underline{u}(\underline{x}), \underline{a}, \underline{x}) = \underline{0}$ with I.C. and B.C.
find the solution $\underline{u}(\underline{x})$, with known parameters $\underline{a}$.
- **History matching, formal definition:**
 - From system of equations $L(\underline{u}(\underline{x}), \underline{a}, \underline{x}) = \underline{0}$ with I.C. and **the solution** $\underline{u}(\underline{x})$ known, determine the boundary conditions and parameter set $\underline{a}$.
 - ▶ Normally some of the B.C.'s and (part of) $\underline{a}$ will be known.

History matching in practice

- $\underline{u}(\underline{x})$ will not be known as a continuous function of a continuous space/time variable, but only at a few points in space at a few times. Mathematically, the solution is unknown **almost everywhere**.
 - The achieved B.C. "solution" cannot be unique.
- In addition the known (sparse) solution $u_i(x_i)$ is not always reliable.
(standard uncertainty, allocation errors, coarse errors).
- The observed quantity may reflect a realisation of the solution which is not possible to model, and therefore would be wrong to honour.
- Our task is to critically utilize the provided historical data in the best possible manner, such that the parameters we determine by the H.M. process are the most likely ones from a physical point of view. (Difficult, difficult,....)

THE HISTORY MATCHING FOUNDATION

- *Our beleive or humble hope is that if we*
 1. *solve our mathematical model with our assumed B.C.s and parameters*
 2. *the simulator obtains a solution which at all points in space / time matches the observed data points*
 3. *this is a strong indication that our assumptions must be correct*
 4. *and hence our model must be able to not only calculate the known past history, but also what is to come (future)*

THE HISTORY MATCHING HYDRA*

- *We are not quite convinced that our mathematical model is entirely reliable*
- *We cannot have absolute faith in the very sparse data we do have*
- *We cannot be absolutely sure that the numerical computations are sufficiently reliable*
 - *Different results on different machines / compilers / Eclipse versions*
- *Even if we do succeed in finding a good match (whatever that is) we cannot claim that it is **the** unique match*
 - *Empirically proven statement*

* Hydra was a many-headed monster fought by Hercules of ancient Greek mythology. Whenever Hercules hew one of the Hydra's heads, two new would grow out.

THE HISTORY MATCHING DILEMMA

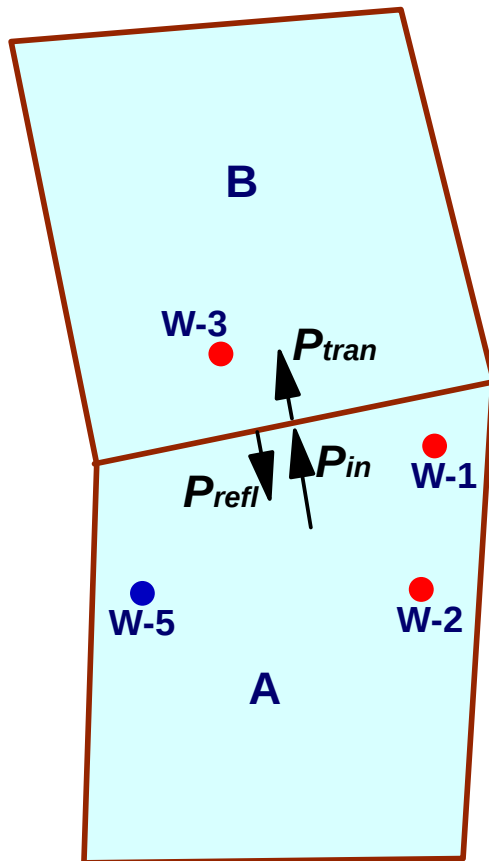
- *When we change our understanding of the geo/petro-model in order to "improve" the current state of our model, we may*
 - *Alter the model data such that they are more in accordance with real data, whether the "real" data are known or not.*
 - *Do unphysical / incomprehensible modifications that after all work (the pragmatic approach)*
 - ▶ *Might be necessary to model non-modellable features (should we??)*
 - ▶ *Might be necessary to counteract software lacks or even bugs, or even hardware shortcomings.*
- *At the bottom line, our history matching process is a combination of*
 - *improving reality in the parameter description*
 - *Q&D fixes of defects in model, solution techniques, SW, and HW.*

After all is said and done...

A model which is based on sound physical principles and matches our available historical data must be better than one that isn't and doesn't .

In some sense it's the best we can do, even though it may be far from perfect.

A SIMPLE YET ILLUSTRATIVE EXAMPLE OF HM PRINCIPLES



Time	Well	Action	Description	Outcome
< 0	W-1, W-2, W-3	Tested		Initial Pressures
0-51	W-1, W-2	Producing	Decline	BHP in W-1, W-2, W-3 Fault flux (transm.) Load compressibility
51-102	W-1, W-2, W-3	Producing		Fault flow interaction Load compressibility
70	W-5	Tested		Ind. zone pressures
> 102	W-5	Injecting	Pressure build up	Unloading compressibility

EXAMPLE cont'd



- *Since well W-3 was deliberately put on production later than W-1 and W-2, we were able to distinguish between*
 - *the pressure drop in block B due to production in block A alone*
 - *production in both blocks.*
- *Moreover the delayed injection start allowed us to distinguish between*
 - *compaction under pure loading (pressure decline)*
 - *expansion under unloading (pressure buildup).*
- *By these two factors we obtained very good transmissibility estimates and compaction curves (and revealed compressibility hysteresis)*

THE EXAMPLE -- POST-ANALYSIS

- *The matching was done with constant permeabilites*
 - *Nobody even considered otherwise at that time*
- *Recent experiments have shown that the permeability in reality is considerably reduced by loading. By taking account of this we would achieve another match, since reduced permeability would slow down the pressure wave.*
- *An example of a "good match" obtained with an inadequate model*
 - *The result is dependant on our base assumptions. If these are wrong we can still get a "match", but of how much value is it?*

ADAPTIVE (AUTOMATIC) HM. The Gradient Method

- Assume you are astray in the forest without the slightest idea of where you are. At this point a gnome suddenly pops up and asks if he can be of assistance. You ask "where is home?".
 - Gnome reply 1: *Well, it's not here*
 - Not very helpful, though it could have been if he'd said "it's here"
 - Gnome reply 2: *It's thataway*
 - A little better, but the road may still be long and thorny
 - Gnome reply 3: *Go 100 yards to the north, and you'll find a footpath which you must follow eastwards for two miles.*
 - And that's what the gradient method is all about.