INTEGRAL – ARB on INT_SC-658: Implications for INTEGRAL operations

Dave Salt

18/11/2020

Current status & understanding of RCS 'issues'

Observations/hypothesis:

1) Book-Keeping and PVT methods show that all tanks have been close to empty for some time (i.e. <5% propellant remaining)
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Conclusions based on above observations/hypothesis:

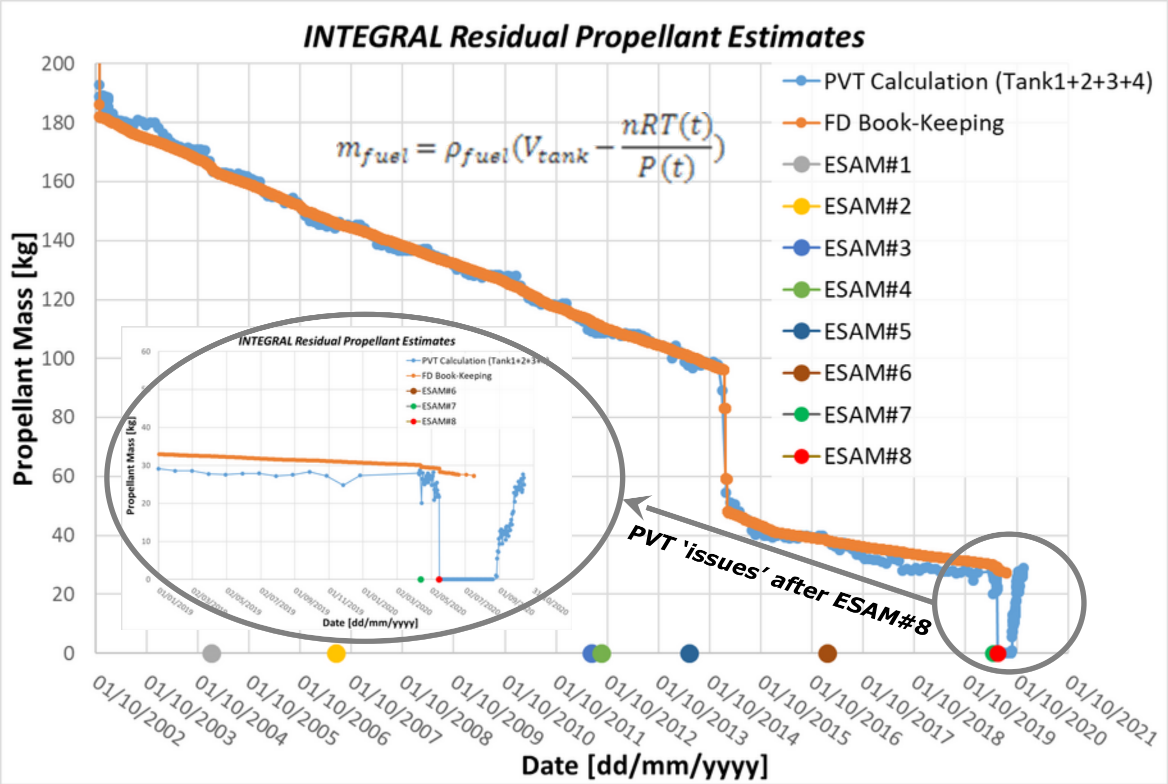
a) most of the remaining propellant may no longer be useable, being either locked within the tank, behind the diaphragm (i.e. reverse migration via permeability), or trapped by the diaphragm in pockets against the tank wall
b) In the latter case, it may eventually become un-trapped as the Delta-P across the diaphragm reduces and its blocking effect is removed
c) A worst case situation means that the only propellant in the feed-lines (~2kg) is available for propulsion

Prognosis/outlook if most of remaining propellant is locked/trapped in the tanks:

i. Only the propellant in the feed-lines is available to support collision avoidance or ESAM
ii. Previously, we measured ~0.5kg per ESAM but this is now likely to be increased (e.g. > x2) due to lower thrust as a result of reduced pressure and GN2 bubbles
iii. The useable propellant is only able to support about 2-to-4 ESAMs, but less if in quick succession

PVT method reanalysed

- The PVT method was reanalysed to better understand differences with Book-Keeping method
  - Data was time-averaged over 1-month intervals to help smooth fluctuations
  - Pressure transducer calibrations fully accounted for voltage, resistance and temperature variations
  - Tank volumes taken from data packs, plus temperature expansion factors
  - Propellant and pressurant masses taken from final Industry loading report
  - Hydrazine density and Nitrogen leakage through tank filling valves are accounted
  - ***Nitrogen absorption*** **by Hydrazine after permeation through the tank membrane and final expulsion via the thrusters is also accounted**
- Reanalysed residual mass estimates now align better with book-keeping
  - Some variation/steps appear seasonal
  - < 10kg difference over last 3 years



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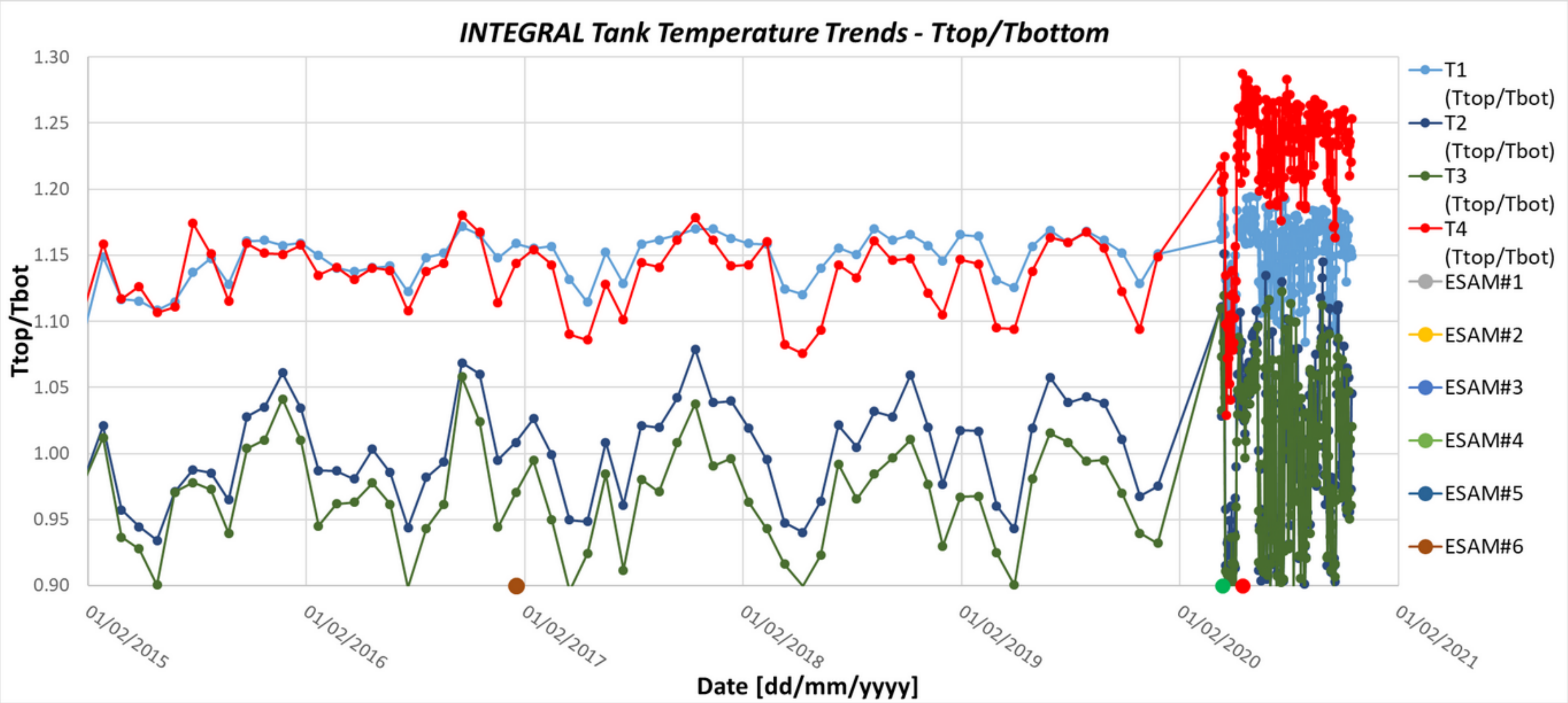
Tank Top/Bottom temperature evolution



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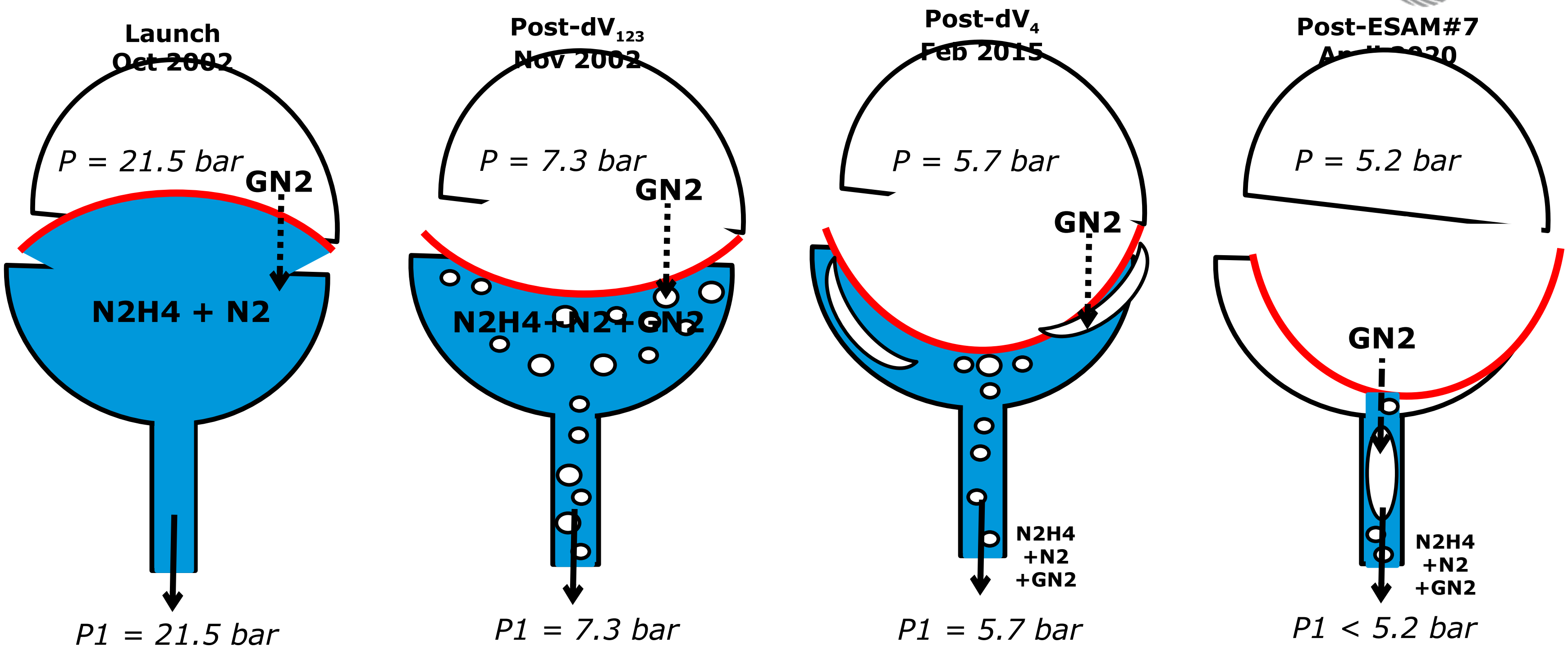
Nitrogen permeation through tank membrane



Nitrogen permeates membrane, gets absorbed into solution within N2H4 and then expelled through thrusters

Pressure drop forces some N2 out of solution, due to super-saturation, to form GN2 bubbles

Nitrogen permeates membrane to form gas bubbles as N2H4 is already fully saturated

Nitrogen continues to permeates membrane to form gas bubbles as N2H4 is already fully saturated

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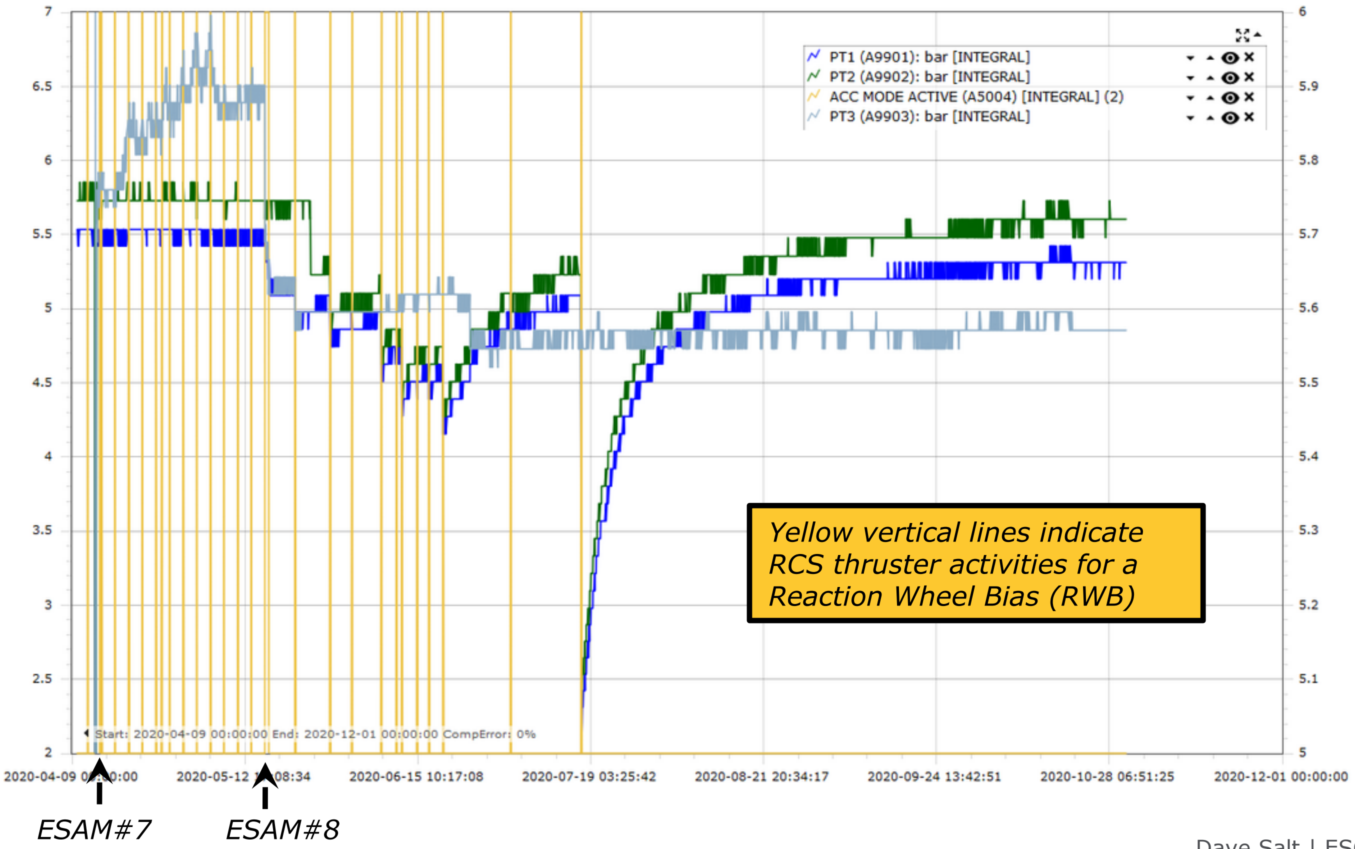
RCS feed-line pressure(s) – since ESAM#7



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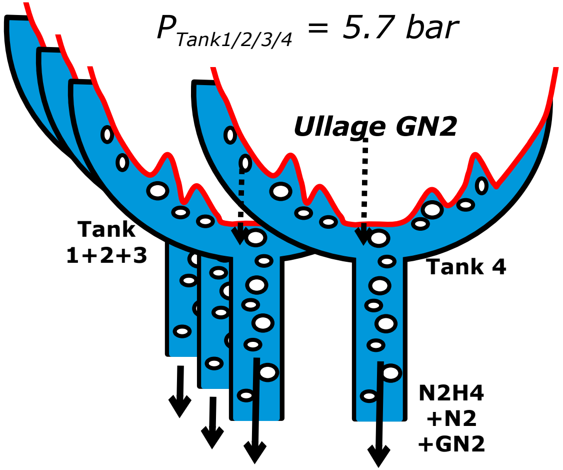
GN2 permeation, Tank ‘plugging’ & PT1 evolution

Pre-ESAM#8
16/05/2020

$P_{Tank1/2/3/4}$ = *5.7 bar*

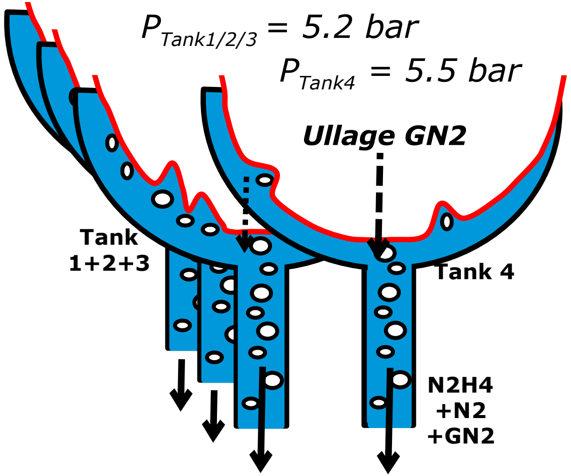


PT1 = 5.7 bar

- **<u>GN2 permeates membrane slowly</u> due to equal pressures on both sides**
- **GN2 bubbles form in RCS feed-lines because N2H4 is fully saturated**
- **Ullage GN2 and bubbles in feed-lines expand adiabatically when propellant and is expelled during RWBs**

Post-ESAM#8
16/05/2020

$P_{Tank1/2/3}$ = *5.2 bar*
P_{Tank4} = *5.5 bar*

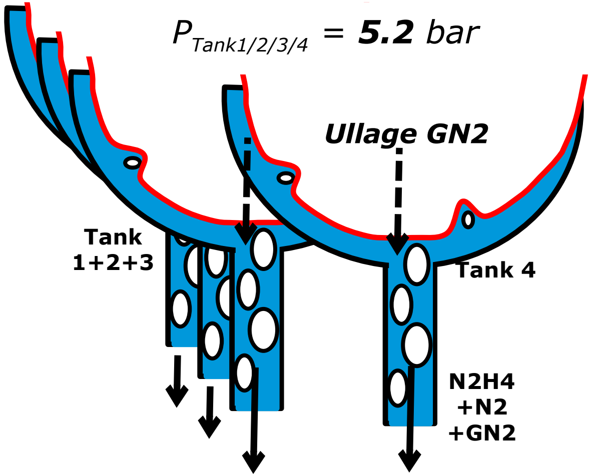


PT1 = 5.2 bar

- **<u>Membrane ‘plugs’ Tank 4 outlet</u> as ullage expands adiabatically when propellant is expelled during ESAM#8**
- **Pressure difference across Tank 4 membrane increases GN2 permeation**
- **Tanks 1, 2 and 3 remain ‘unplugged’ allowing ullage to expand adiabatically**

Post-RWB
17/07/2020

$P_{Tank1/2/3/4}$ = ***5.2** bar*



*PT1 = **2.6** bar*

- **Membranes now ‘plug’ <u>all</u> tanks**
- **Only GN2 bubbles in the RCS feed-lines can expand adiabatically as ullage GN2 is isolated, resulting in <u>*massive drop in PT1*</u>**
- **Large pressure difference across all tank membranes increases GN2 permeation, <u>slowly equalising pressure differences</u>**

Modelling PT1 evolution to support hypothesis

1) The model assumes the ‘forcing’ can be expressed as a change in pressure per day and is simply a function of the pressure difference across the ‘plug’.
2) The initial PT1 pressure value was taken from the measured value after the bias and then simply increased incrementally over time, based upon an appropriate ‘forcing’ value.
3) However, it became clear during the development process that one ‘forcing’ value was inadequate to enable the model to match the PT1 telemetry values.
4) We therefore introduced a number of ‘forcing’ values – four in total – that switched over as a function of the modelled pressure and were tuned to match the model with the telemetry.
5) Surprisingly, these four values gave the best fit when they were exact multiples of the smallest (i.e. 0.0375, 0.0750, 0.1125, 0.1500), which supports the idea that the four tanks become ‘plugged’ or ’unplugged’ in sequence.
6) Having shown that this model matched the recovery of PT1 after the last bias, we then applied it across all of the recent PT1 data since before ESAM#7.
7) The resulting plot shows that the model also gives a very good match over the full range of data and so supports the hypothesis presented herein.
8) The derived ‘forcing’ values were also used to estimate a value for the diaphragm’s permeability (8.4E-08 g/s/delta_bar/cm), which is close to the Industry value (6.3E-08 ccSTP cm/cm2/s/bar)

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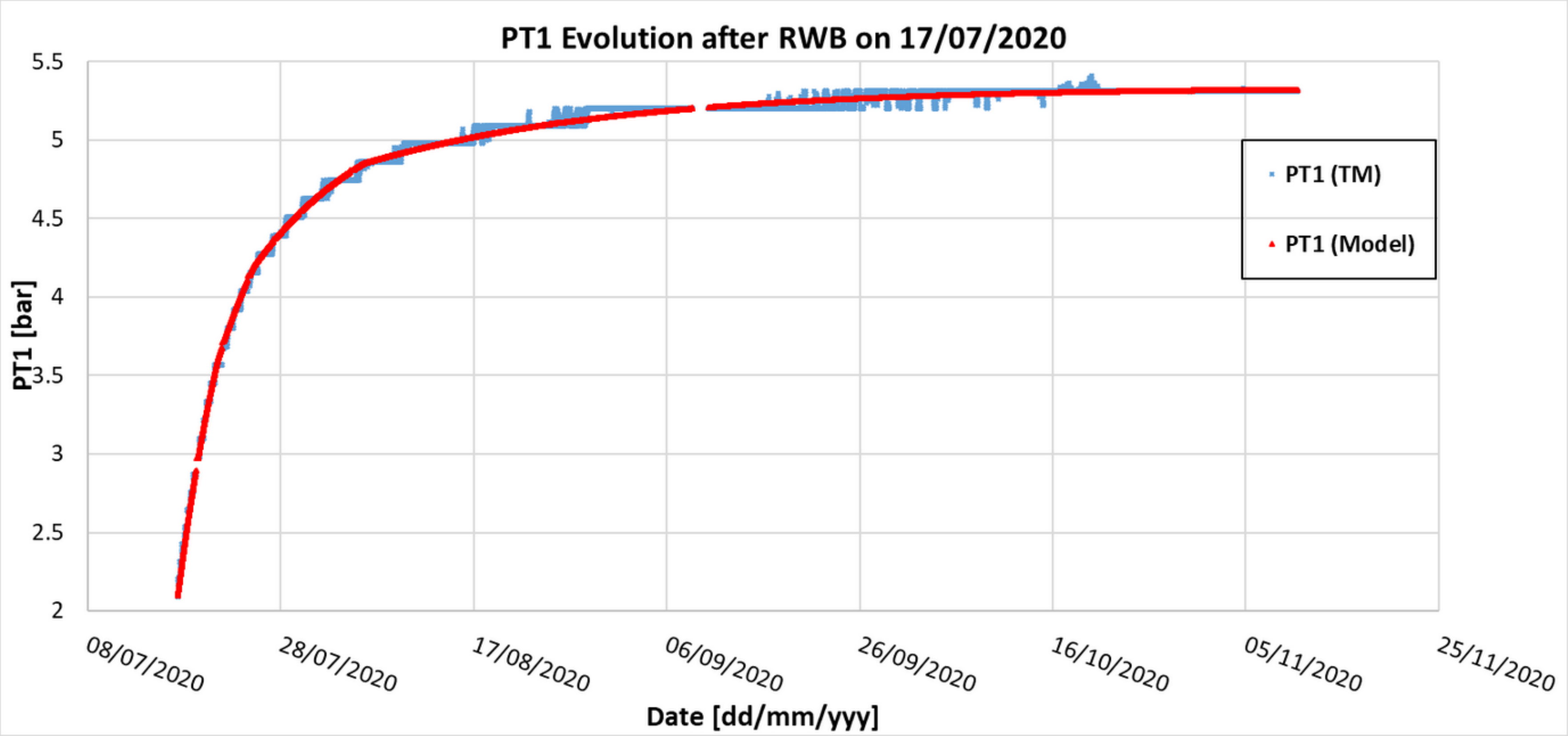

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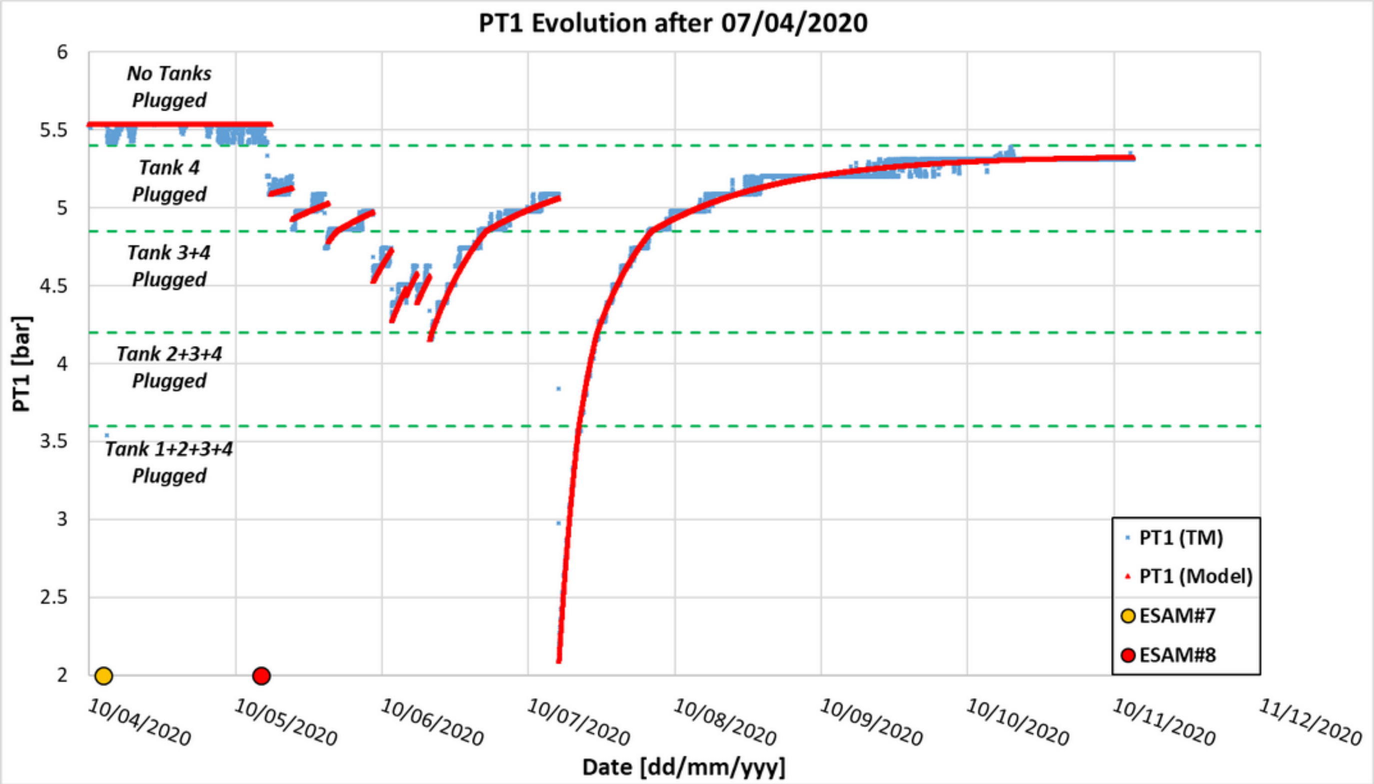

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