# CATERPILLAR 1K TEST: PRELIMINARY ANALYSIS OF POTENTIAL SHIFT OVER TIME

August 25th, 2015

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Performance you can rely on.

Infineum

# Outline

- Data
- Plots by parameter
- Data Analysis by parameter
- Main remarks

# Data overview:

- Chart = Yes/ No

| | CHART | N Rows |
|---|---|---|
| 1 | N | 457 |
| 2 | Y | 647 |

Plots presented next: Target 809-1 and 811-1: 08 1993 (marked as “T”)

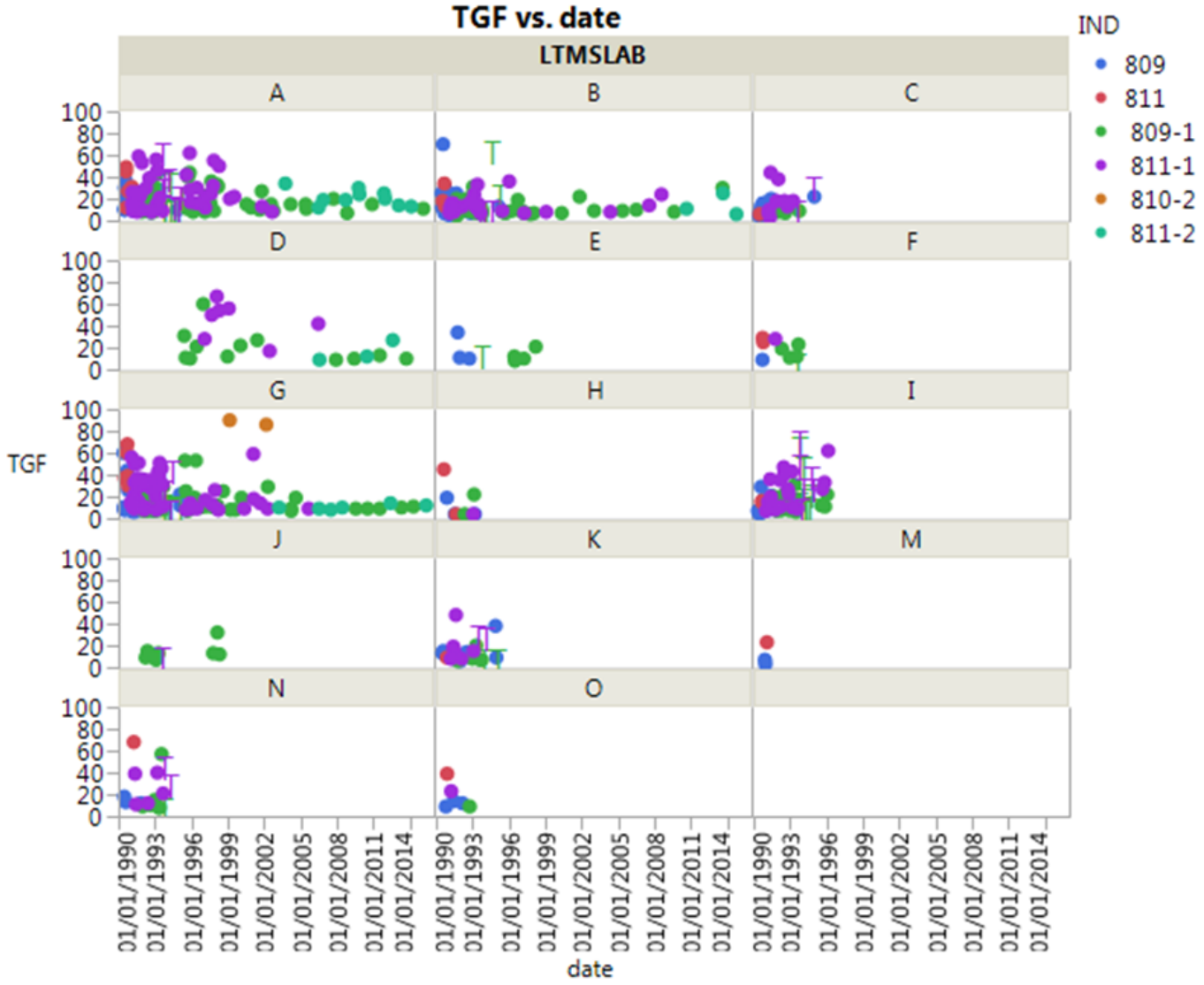
Labs running more recently: A, B, D, G

Labs without target tests: D, H, M, O

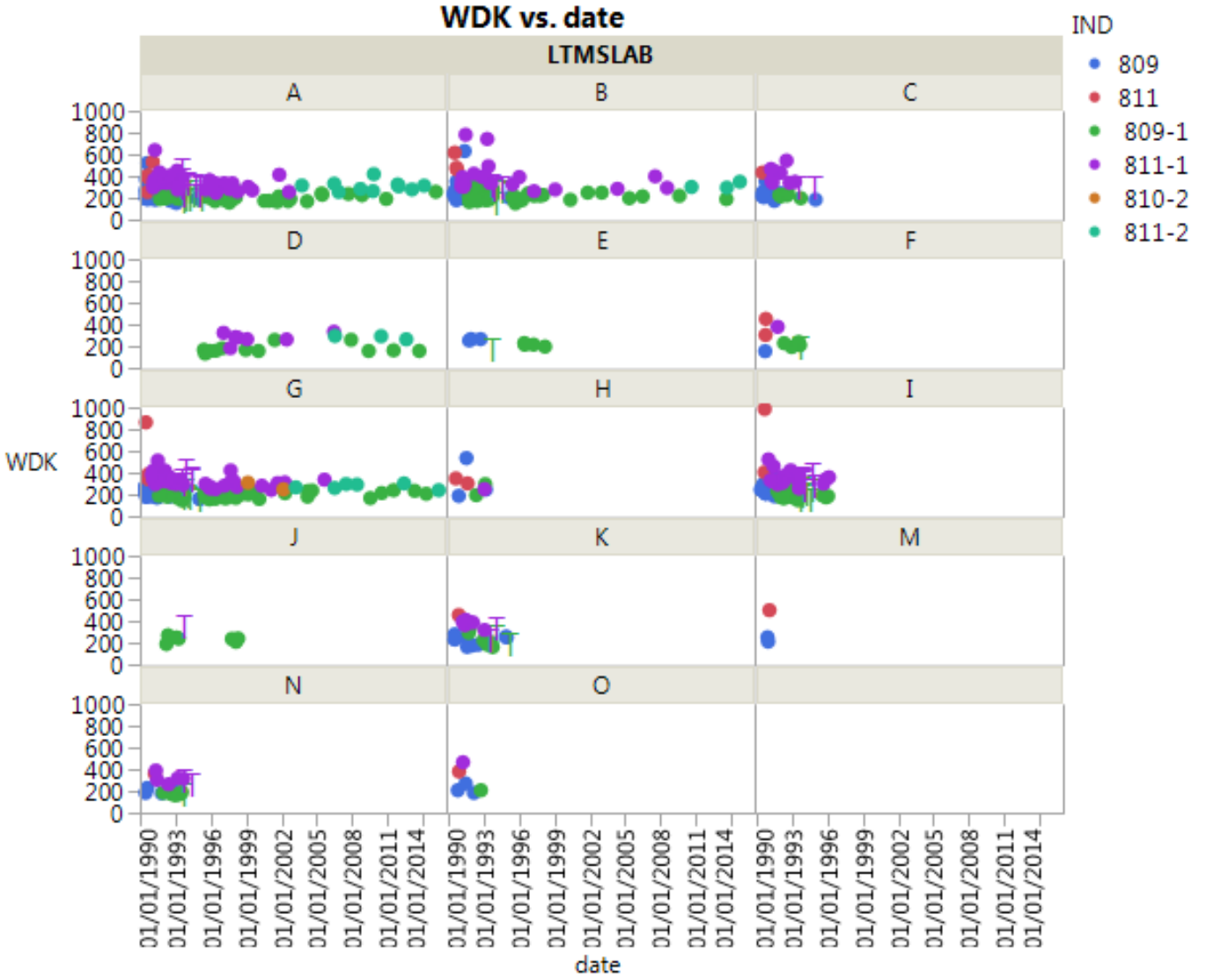
| | | |
|---|---|---|
| 2 | 1Y3555 | 1 |
| 3 | 1Y3555G | 1 |
| 4 | 1Y-35 | 1 |
| 5 | 1Y355 | 79 |
| 6 | 1Y3555 | 63 |
| 7 | 1Y35555 | 1 |
| 8 | 1Y3555G | 27 |
| 9 | 1Y3555-G | 1 |
| 10 | 1Y3556 | 1 |
| 11 | 1Y355G | 2 |

All liners coded by one of the names on the list were assumed to be1Y3555

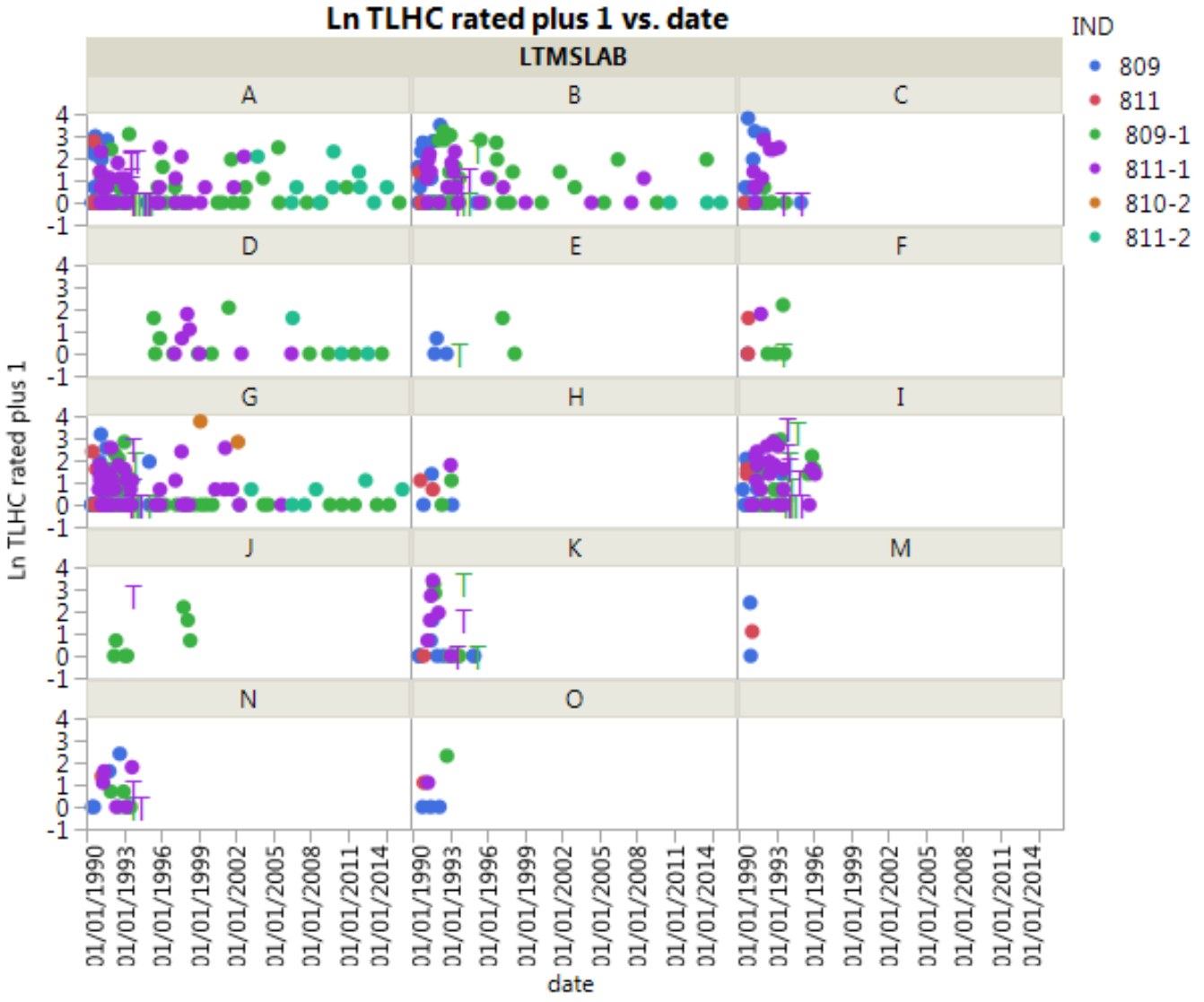
# TGF: Chart = Yes; including 809/811 and re-blends



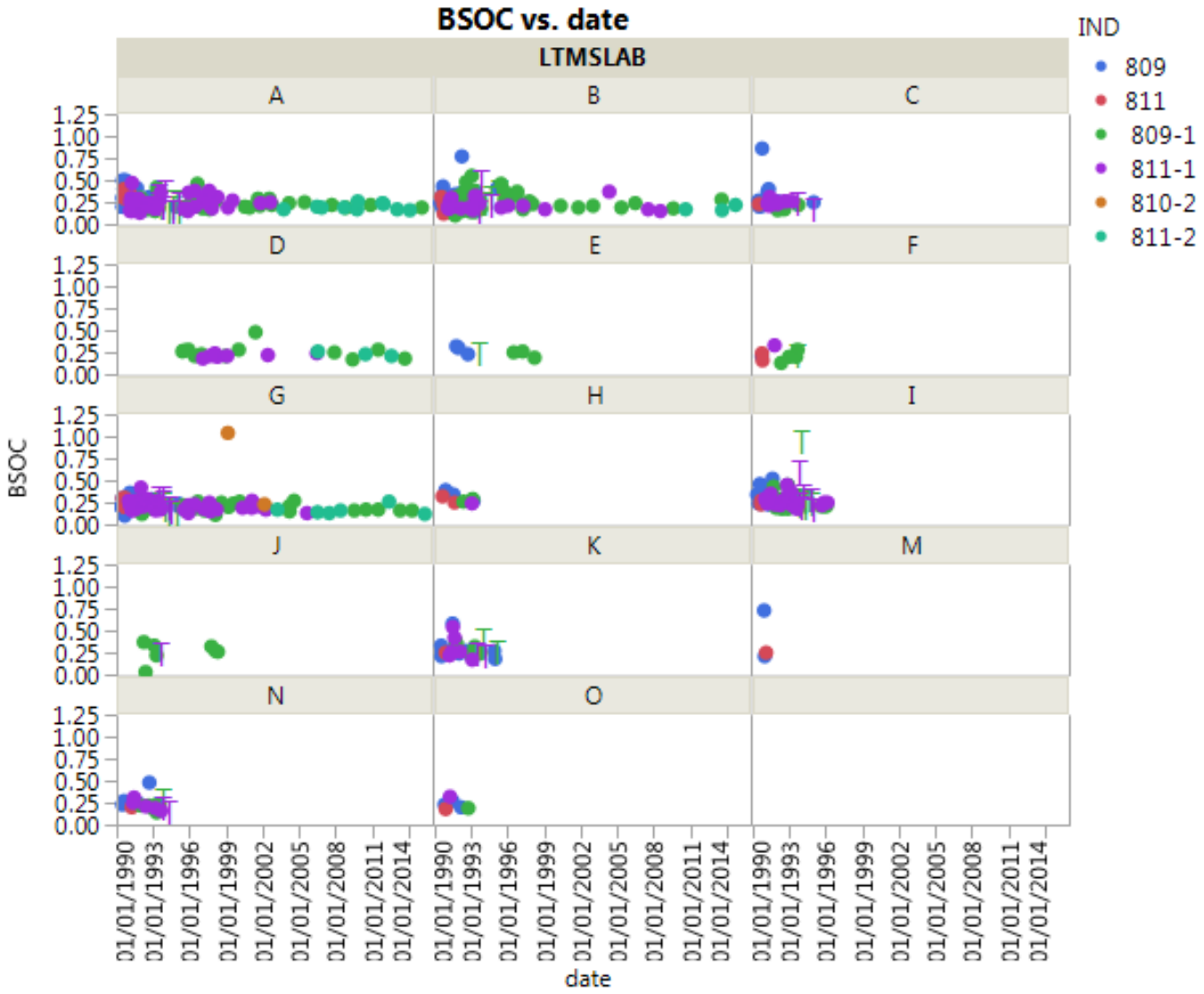
# Data (cont.)
## WDK: Chart = Yes; including 809/811 and re-blends



# Data (cont.): Top Land Heavy Carbon transformed
## Chart = Yes; including 809/811 and re-blends



# Data (cont.)
# Oil Consumption: Chart = Yes; including 809/811 and re-blends



# Defining the working data set for modeling

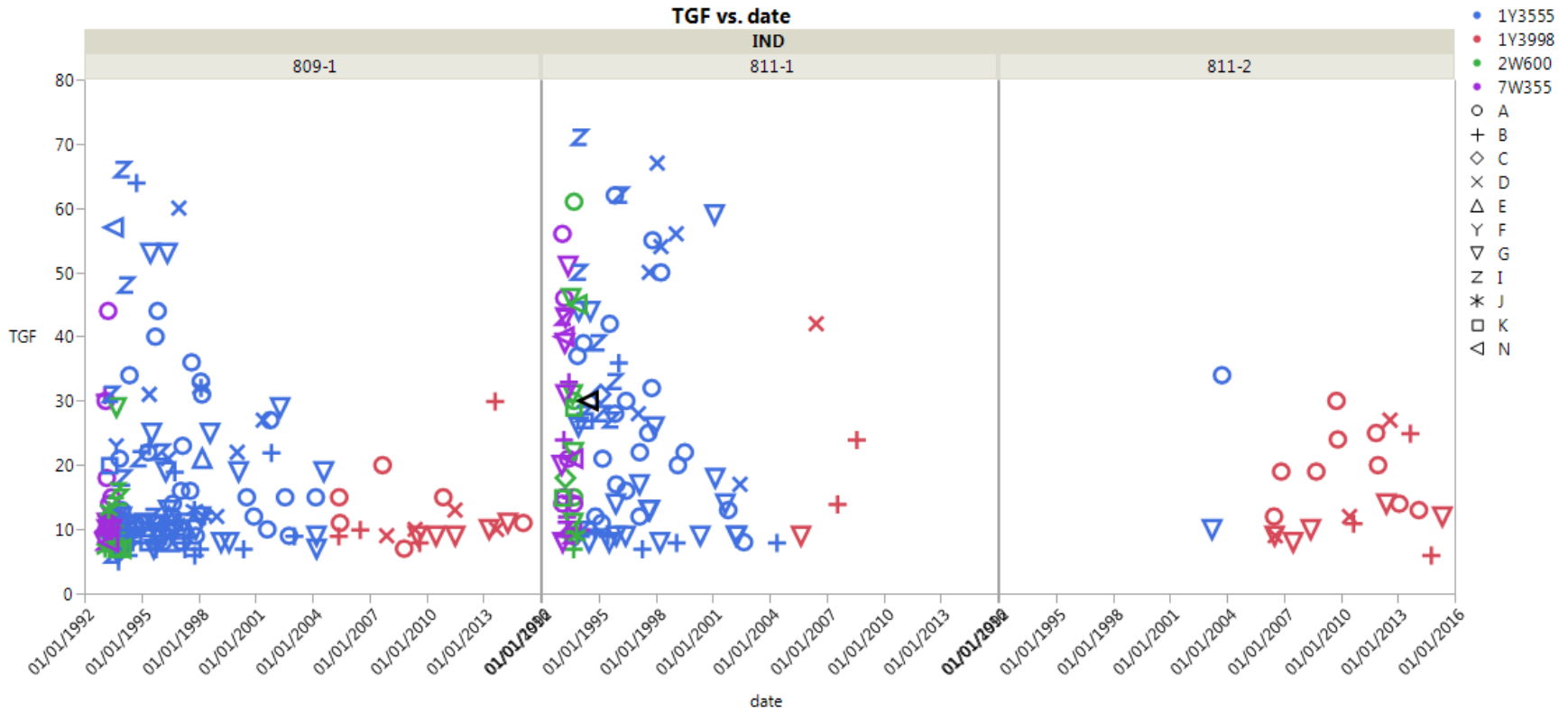
- 1K started in 1990; initially lot of tests were being assigned chart = N
- Liners:
  - 1Y702 (at start of the test)
  - 7W355 (introduced in 1991)
  - 2W600 (introduced in 1992)
  - 1Y3555 (introduced in 1993)
  - 1Y3998 (introduced in 2005)
- 809-1 and 811-1 Targets, collected between 08/31/1993 to 05/20/1995, have been defined with multiple liners: 30 tests for each oil. One liner is missing.

| | | LINER | Liner target | N Rows |
|---|---|---|---|---|
| T | 1 | 7W355 | Target | 3 |
| T | 2 | 2W600 | Target | 10 |
| T | 3 | 1Y3555 | Target | 46 |
| T | 4 | | Target | 1 |

- Working data:
  - Started with 301 tests from 1993 forward and chart = Yes. This subset included tests with liners 7W355 and 2W600 and I prefer to focus on the latest liners: 1Y3555 and 1Y3998. By the way, the conclusions are the same using 301 or 223 tests.
  - Went down to 223, after deciding to use Target tests with whatever liners they had plus all tests after last target test ran (which corresponds to all tests after 06/02/1995).
  - I created a new column called Liner/Target with levels: Target, 1Y3555 and 1Y3998

# TGF vs. date by Oil and Lab

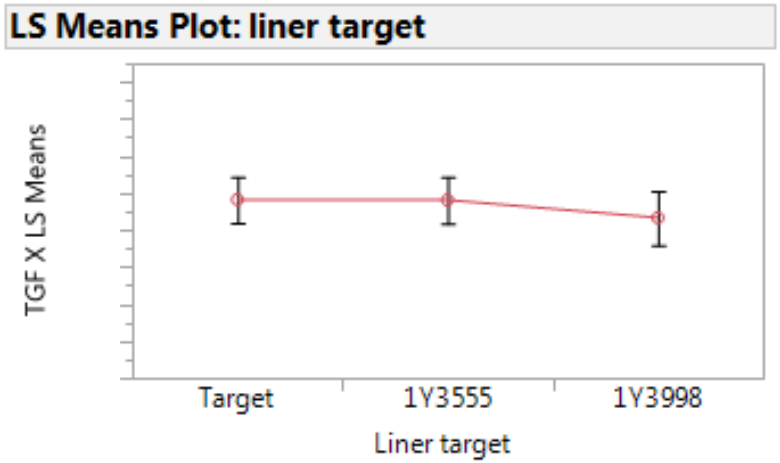
n=301*




*includes liners 7W355, 2W600 and beginning of 1Y3555 before 809-1 and 811-1 targets were set

# TGF transformed to achieve constant variance n=223

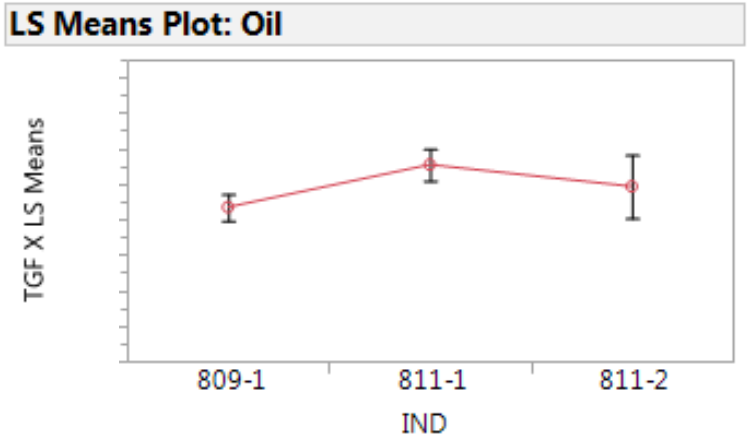
## Model 1




Model 1: Lab, Oil, Liner target*

No evidence that Target, 1Y3555 and 1Y3998 differ

## Model 1: similar estimates for model 2




Model 2: Lab, Oil, Date (normalized) n=223

The coefficient for Date is negative, (-0.880067), not statistically significant (t ratio=-1.27)

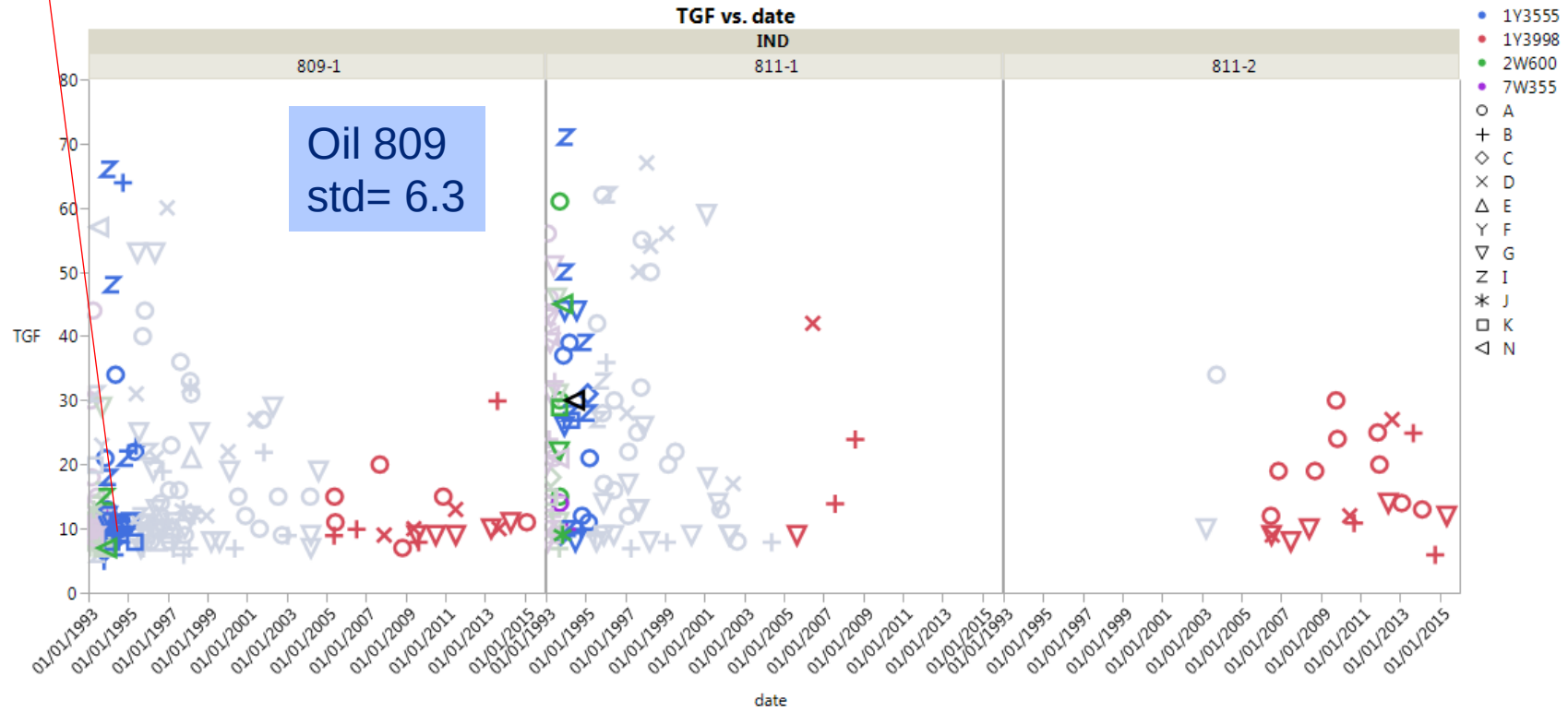
# TGF: looking at variability

## Pooled standard deviation for tests with most recent liner 1Y3998

At Target, 50% of the data is below 11

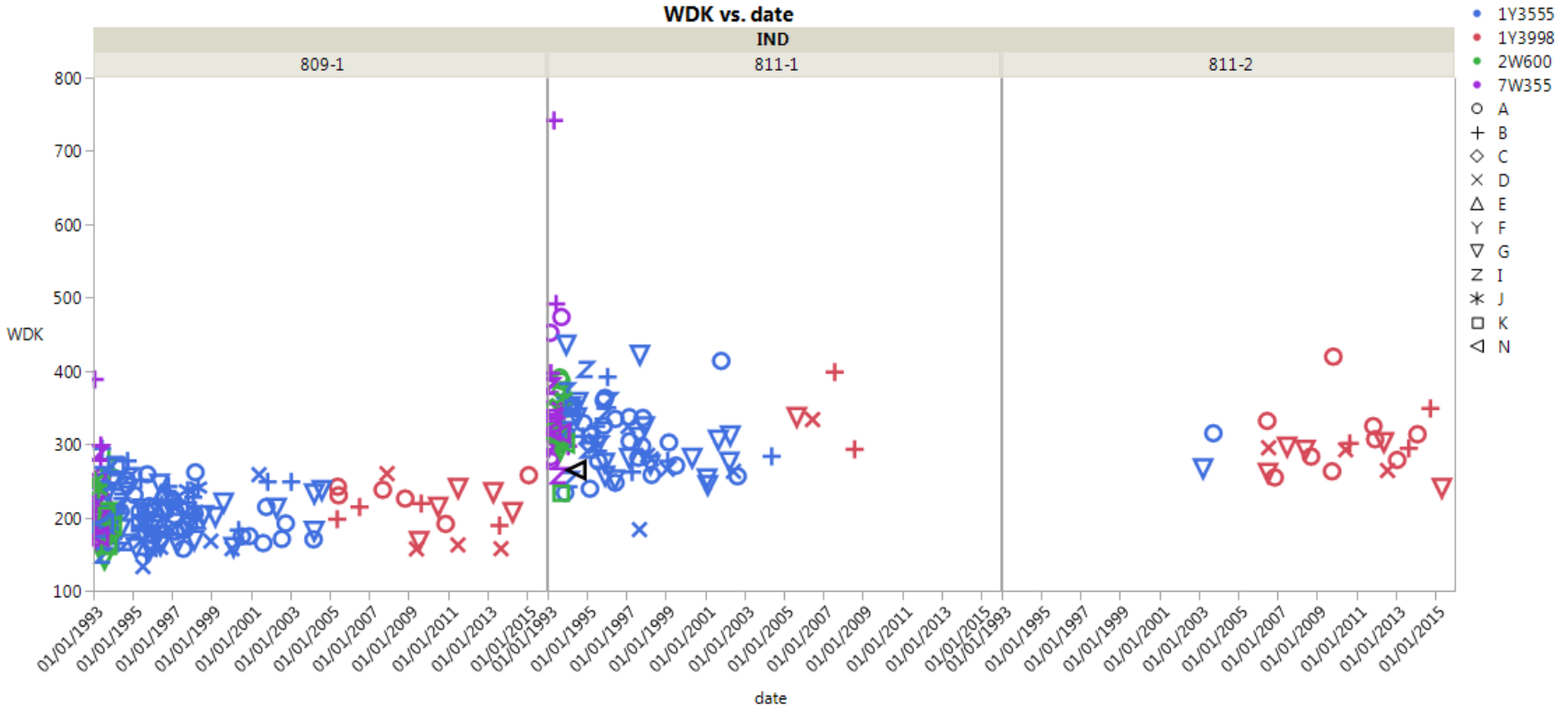
| TGF | | | | | | incl. 811-1 |
|---|---|---|---|---|---|---|
| Oil | Liner | N | Mean | Std | pooled std | pooled std |
| 809-1 | 1Y3998 | 19 | 11.89474 | 5.332237 | 6.317585 | 7.268923 |
| 809-1 | Target | 30 | 17.46667 | 15.6728 | | |
| 811-1 | 1Y3998 | 4 | 22.25 | 14.5688 | | |
| 811-1 | Target | 30 | 27.33333 | 16.57654 | | |
| 811-2 | 1Y3998 | 20 | 15.95 | 7.126489 | | |

Std changed over time



# WDK vs. date by Oil and Lab

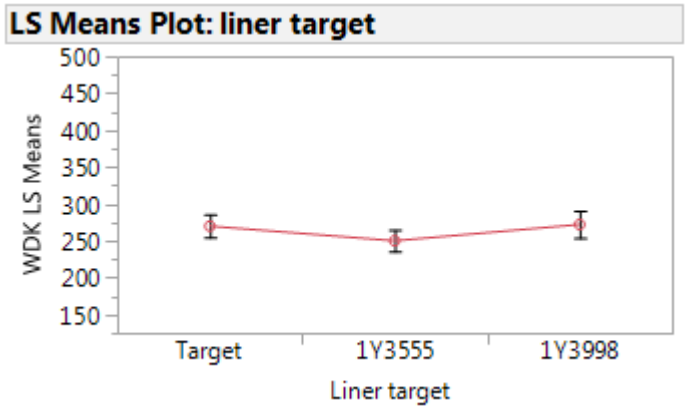
n=301*




*includes liners 7W355, 2W600 and beginning of 1Y3555 before 809-1 and 811-1 targets were set

# LN WDK: transformed to achieve constant variance n=223

## Model 1

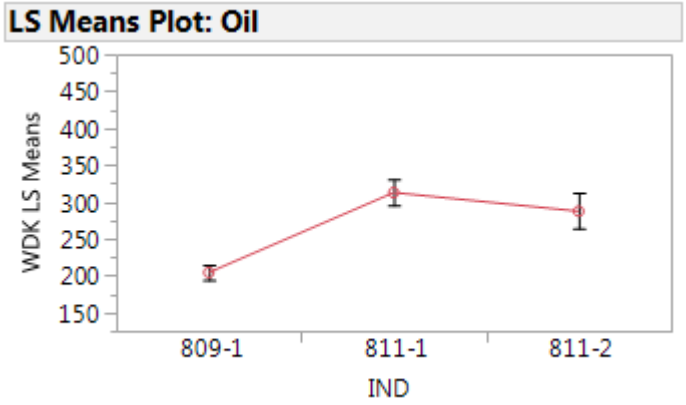



| Liner Target | | | Least Sq Mean |
|---|---|---|---|
| 1Y3998 | A | | 272.2 |
| Target | A | | 270 |
| 1Y3555 | | B | 250.1 |

Model 1: Lab, Oil, Liner target*
Note that 17328, high test from Lab B - liner 7W355 is not part of the target and not included in this subset.

No evidence that Target and 1Y3998 differ

## Model 1: similar estimates for model 2




| Oil | | | Least Sq Mean |
|---|---|---|---|
| 811-1 | A | | 312.7 |
| 811-2 | A | | 287.5 |
| 809-1 | | B | 204.4 |

Model 2: Lab, Oil, Date (normalized)

The coefficient for Date is positive (+0.0097401), not statistically significant (t ratio=+0.73)

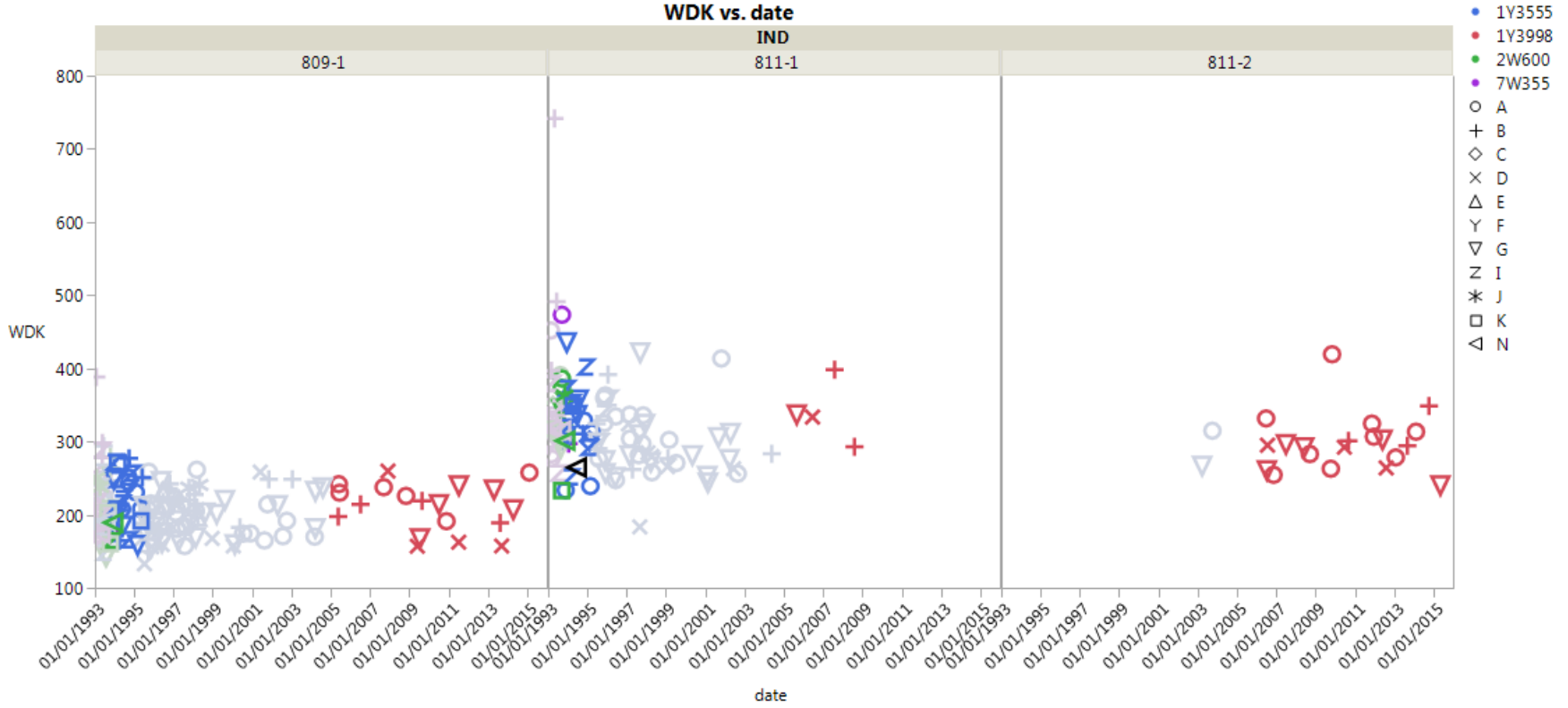
* Defined in slide 8

# WDK: looking at variability

## Pooled standard deviation for tests with most recent liner 1Y3998

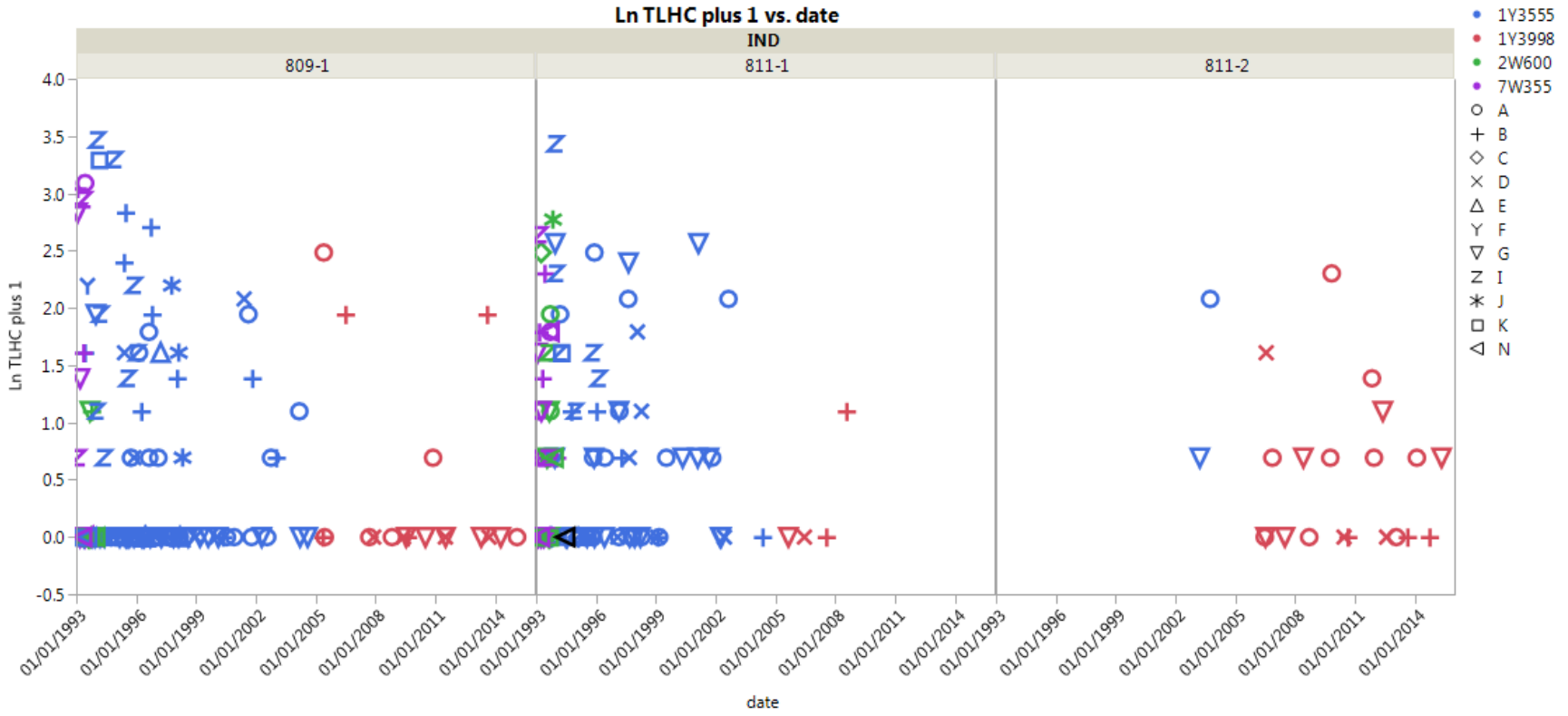
| WDK | | | | | | incl. 811-1 |
|---|---|---|---|---|---|---|
| IND | Liner target | N | Mean | Std | pooled std | pooled std |
| 809-1 | Target | 30 | 216.4 | 35.64721 | 36.25158 | 36.84602 |
| 809-1 | 1Y3998 | 19 | 211.0421 | 32.78203 | | |
| 811-1 | Target | 30 | 327.7433 | 55.91403 | | |
| 811-1 | 1Y3998 | 4 | 340.825 | 43.51478 | | |
| 811-2 | 1Y3998 | 20 | 298.36 | 39.25668 | | |

Not suggesting change in std, but thought you would ask questions about pooled std



# LN (TLHC +1) vs. date by Oil and Lab
## Non critical

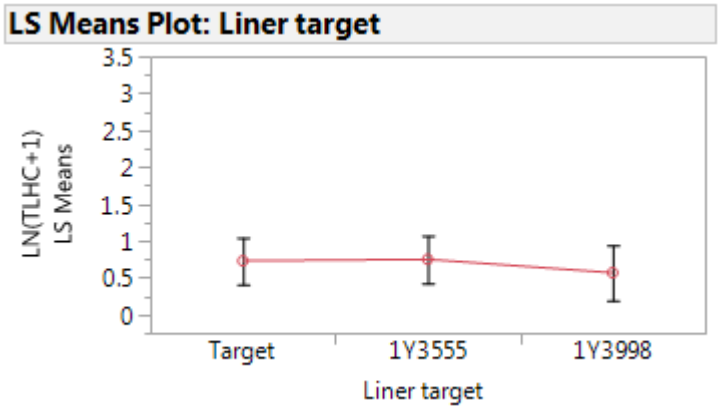
n=301*




*includes liners 7W355, 2W600 and beginning of 1Y3555 before 809-1 and 811-1 targets were set

# LN (TLHC+1): n=223

## Model 1

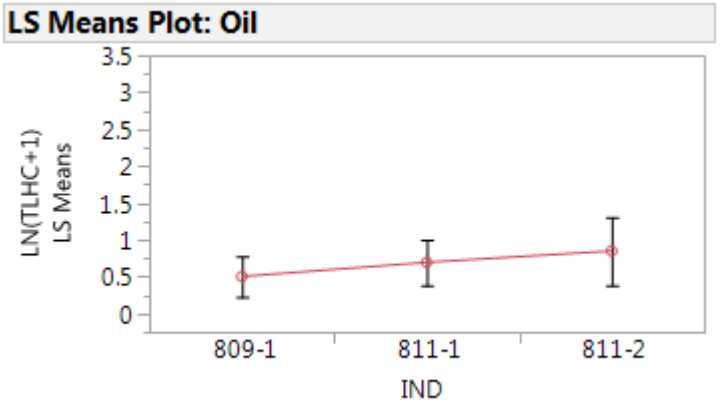



| Level | | Least Sq Mean |
|---|---|---|
| 1Y3555 | A | 0.74969936 |
| Target | A | 0.72933900 |
| 1Y3998 | A | 0.56808021 |

Model 1: Lab, Oil, Liner/Target*

No evidence that Target, 1Y3555 and 1Y3998 differ

## Model 1: similar estimates for model 2




| Level | | Least Sq Mean |
|---|---|---|
| 811-2 | A | 0.84911024 |
| 811-1 | A | 0.69452440 |
| 809-1 | A | 0.50348394 |

Model 2: Lab, Oil, Date
(normalized)

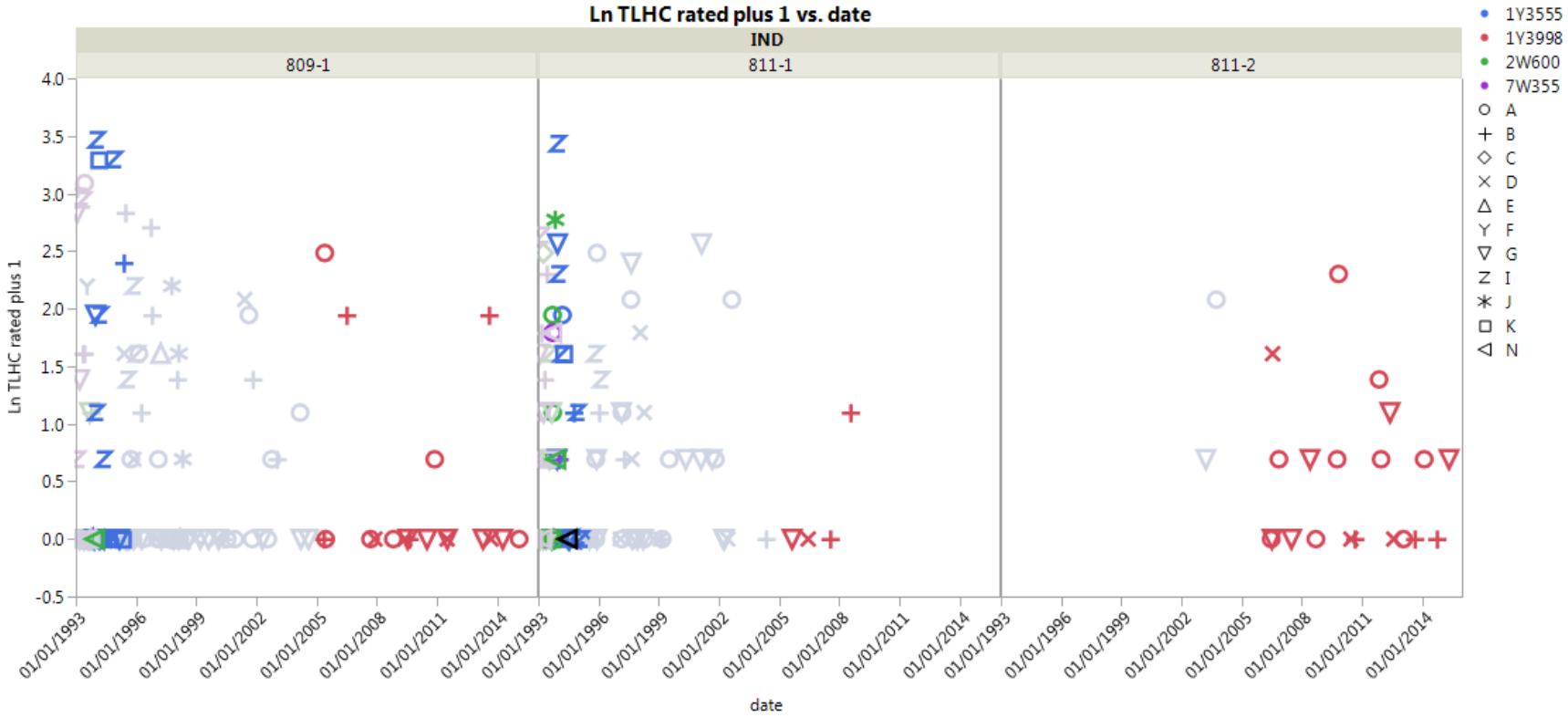
The coefficient for Date is negative, (-0.059892), not statistically significant (t ratio= -0.85)

* Defined in slide 8

# LN (TLHC+1): looking at variability

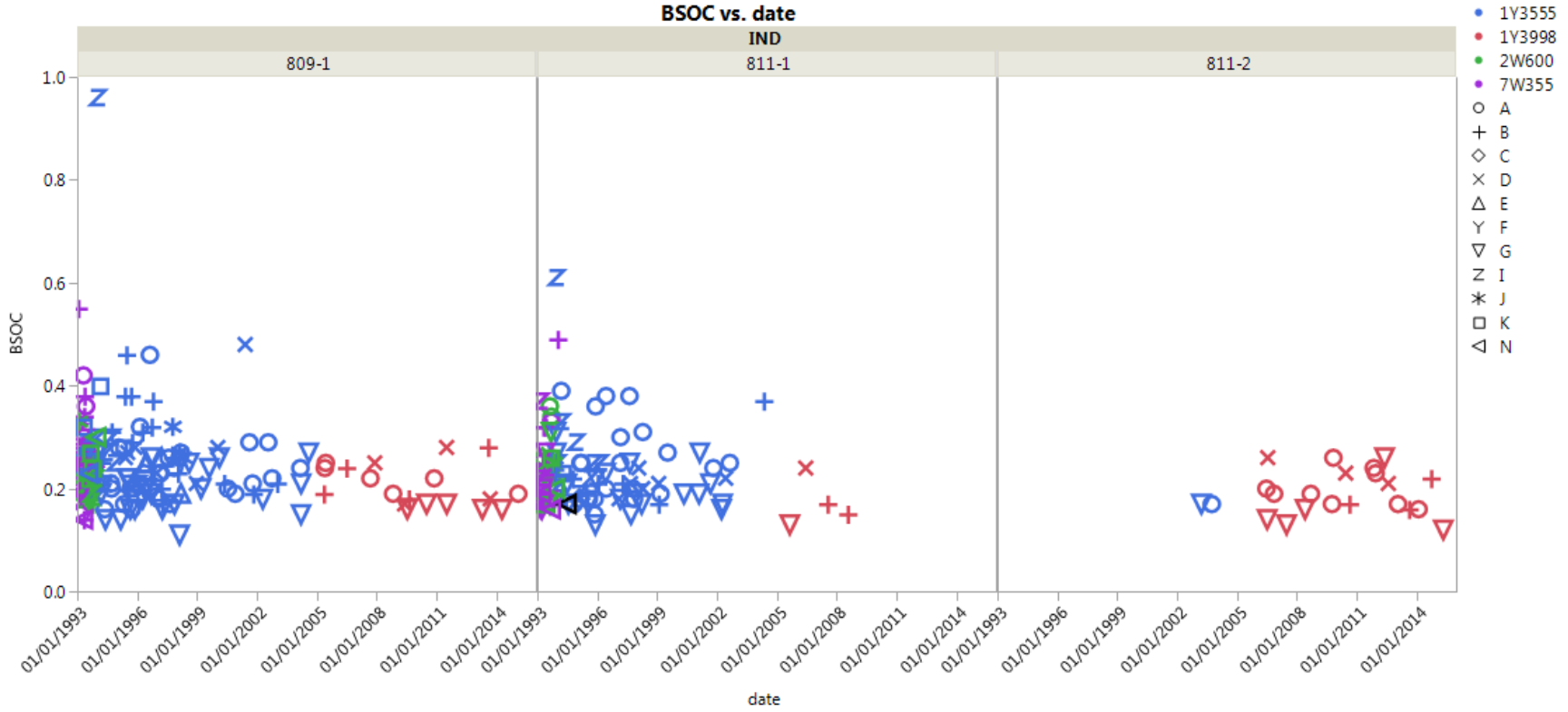
## Pooled standard deviation for tests with most recent liner 1Y3998

| | | | | | | incl. 811-1 |
|---|---|---|---|---|---|---|
| Oil | Liner target | N | Mean | Std | pooled std | pooled std |
| 809-1 | Target | 30 | 0.604629 | 1.141378 | 0.733928 | 0.721721 |
| 809-1 | 1Y3998 | 19 | 0.372099 | 0.802692 | | |
| 811-1 | Target | 30 | 0.868166 | 1.021422 | | |
| 811-1 | 1Y3998 | 4 | 0.274653 | 0.549306 | | |
| 811-2 | 1Y3998 | 20 | 0.527791 | 0.662229 | | |



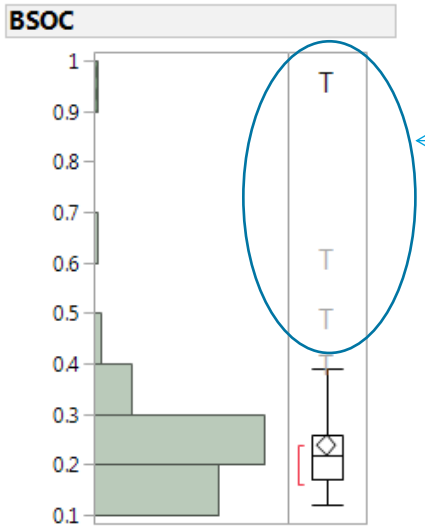
# Oil Consumption: vs. date by Oil and Lab
## Non critical

n=301




The analysis indicated that there may be a trend going down, likely associated with liner 1Y3998. Further analysis will be done and a correction will be proposed

# Oil consumption: more details

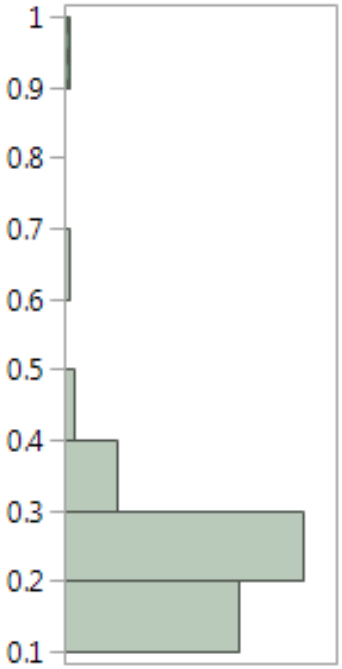



| Quantiles | | |
|---|---|---|
| 100.0% | maximum | 0.96 |
| 99.5% | | 0.96 |
| 97.5% | | 0.538 |
| 90.0% | | 0.31 |
| 75.0% | quartile | 0.26 |
| 50.0% | median | 0.22 |
| 25.0% | quartile | 0.17 |
| 10.0% | | 0.16 |
| 2.5% | | 0.13 |
| 0.5% | | 0.12 |
| 0.0% | minimum | 0.12 |

| Summary Statistics | |
|---|---|
| Mean | 0.2383495 |
| Std Dev | 0.103138 |
| Std Err Mean | 0.0101625 |
| Upper 95% Mean | 0.2585068 |
| Lower 95% Mean | 0.2181923 |
| N | 103 |

Part of the Target, above the 0.5 g/kWh

Zoom of the plot




## LTMS excerpt for 1K

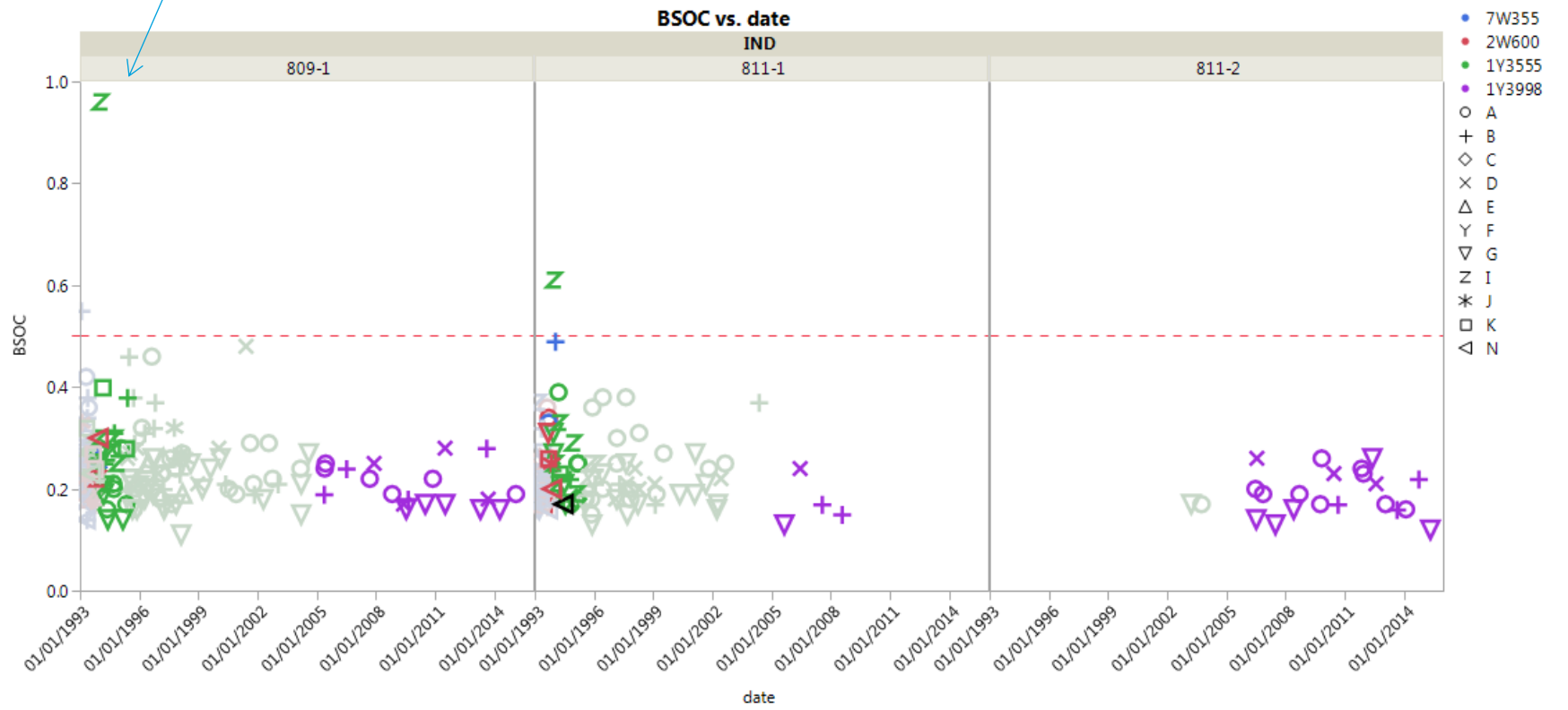
- Exceed Shewhart test stand chart limit for severity (all parameters except Average Oil Consumption)
  - Conduct an additional calibration test.
- Exceed 0.5 g/kWh Average Oil Consumption
  - Conduct an additional calibration test.

# Oil Consumption: Mean and standard deviation by oil/liner combination

excludes 18515 from lab I

| BSOC | | | | | | incl. 811-1 |
|---|---|---|---|---|---|---|
| IND | Liner target | N= 222 | Mean | Std | pooled std | pooled std |
| 809-1 | Target | 29 | 0.245862 | 0.063948 | 0.04234 | 0.04278 |
| 809-1 | 1Y3998 | 19 | 0.205263 | 0.040739 | | |
| 811-1 | Target | 30 | 0.266667 | 0.09693 | | |
| 811-1 | 1Y3998 | 4 | 0.1725 | 0.047871 | | |
| 811-2 | 1Y3998 | 20 | 0.1935 | 0.043803 | | |

| BSOC | | | | | |
|---|---|---|---|---|---|
| Oil | Liner target | N= 223 | Mean | Std | pooled |
| 809-1 | Target | 30 | 0.269667 | 0.144735 | 0.042 |
| 809-1 | 1Y3998 | 19 | 0.205263 | 0.040739 | |
| 811-1 | Target | 30 | 0.266667 | 0.09693 | |
| 811-1 | 1Y3998 | 4 | 0.1725 | 0.047871 | |
| 811-2 | 1Y3998 | 20 | 0.1935 | 0.043803 | |



# BSOC target clarification

- It seems that for Target test 15233, the BSOC value used for calculating the target is 0.22 when the ltms published value is 0.26

| Lab | Testkey | VALID | OIL | REPORT | TGF | WDK | TLHC | BSOC | BSOC ltms | diff BSOC |
|---|---|---|---|---|---|---|---|---|---|---|
| E | 15233 | AC | 809-1 | 931115 | 12 | 190.2 | 0 | 0.22 | 0.26 | 0.04 |

- The table below reflects this difference:
  - Target mean is 0.268 and std = 0.145
  - My calculations generate a mean = 0.270 and std = 0.145

| BSOC | | | | | | incl. 811-1 |
|---|---|---|---|---|---|---|
| Oil | Liner target | N= 223 | Mean | Std | pooled std | pooled std |
| 809-1 | Target | 30 | 0.269667 | 0.144735 | 0.04234 | 0.04278 |
| 809-1 | 1Y3998 | 19 | 0.205263 | 0.040739 | | |
| 811-1 | Target | 30 | 0.266667 | 0.09693 | | |
| 811-1 | 1Y3998 | 4 | 0.1725 | 0.047871 | | |
| 811-2 | 1Y3998 | 20 | 0.1935 | 0.043803 | | |

# Main remarks

- SP may want to review the standard deviation for TGF. Standard deviations seem to have gone back to levels seen before for 809. The standard deviations for WDK and Log (TLHC+1) did not change as much as TGF's.
- I will be happy to propose a correction factor for Oil consumption – non critical, if necessary
- Please, contact me if you have any questions or want to see more details about the analysis. I did not include all the details to keep the number of slides down.

# APPENDIX

# Refer to LTMS

## 1K Reference Oil Targets

| 1K Reference Oil Targets | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Oil | n | Effective Dates | | WDK | | TGF | | TLHC[3] | | BSOC | |
| | | From[1] | To[2] | $\bar{X}$ | s | $\bar{X}$ | s | $\bar{X}$ | s | $\bar{X}$ | s |
| 809 | 30 | 5-6-90 | *** | 219.2 | 41.9 | 12.3 | 6.3 | 0.398 | 0.9 | 0.272 | 0.117 |
| 809-1 | 30 | 8-16-91 | *** | 216.4 | 35.6 | 17.5 | 15.7 | 0.605 | 1.1 | 0.268 | 0.145 |
| 810-2[5] | -- | 2-1-98 | 12-31-99 | 247.4 | 38.4 | 53.8 | 22.1 | 2.065 | 1.4 | 0.309 | 0.212 |
| | 8 | 1-1-00 | *** | 261.3 | 38.8 | 55.3 | 20.2 | 1.935 | 1.7 | 0.375 | 0.331 |
| 811[4] | -- | 7-1-90 | 8-20-91 | 327.7 | 55.9 | 27.3 | 16.6 | 0.868 | 1.0 | 0.267 | 0.097 |
| 811-1 | 30 | 1-1-91 | *** | 327.7 | 55.9 | 27.3 | 16.6 | 0.868 | 1.0 | 0.267 | 0.097 |

1 Effective for all tests completed on or after this date.
2 *** = currently in effect.
3 Transformation for TLHC is ln(TLHC+1)
4 Targets based on 811-1.
5 Targets based on 810-1.

## 1K: No correction factors

APPENDIX B (continued)
HISTORY OF INDUSTRY CORRECTION FACTORS

| Test Area | Effective | | Condition | Description |
|---|---|---|---|---|
| | From | To | | |
| 1M-PC | None | | All Tests | None |
| 1K | None | | All Tests | None |

# LTMS

WEIGHTED DEMERITS
Unit of Measure: Demerits
CRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809 | 219.2 | 41.9 |
| 809-1 | 216.4 | 35.6 |
| 811-1 | 327.7 | 55.9 |

TOP GROOVE FILL
Unit of Measure: Percent
CRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809 | 12.3 | 6.3 |
| 809-1 | 17.5 | 15.7 |
| 811-1 | 27.3 | 16.6 |

TOP LAND HEAVY CARBON
Unit of Measure: LN(TLHC+1)
NONCRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809 | 0.398 | 0.9 |
| 809-1 | 0.605 | 1.1 |
| 811-1 | 0.868 | 1.0 |

AVERAGE OIL CONSUMPTION
Unit of Measure: g/kW-h
NONCRITICAL PARAMETER

| Reference Oil | Mean | Standard Deviation |
|---|---|---|
| 809 | 0.272 | 0.117 |
| 809-1 | 0.268 | 0.145 |
| 811-1 | 0.267 | 0.097 |

- Exceed EWMA laboratory chart action limit for severity (all parameters noted below)
  - Calculate laboratory Severity Adjustment (SA) for each parameter that exceeds action limit, using the current laboratory EWMA ($Z_i$) as follows:

Weighted Demerits: $SA = (-Z_i) \times (35.6)^*$
Top Groove Fill: $SA = (-Z_i) \times (15.7)^*$
Top Land Heavy Carbon: $SA = (-Z_i) \times (1.1)^*$

* s based on reference oil 809-1

# Data n= 301: excluding 809/811 data

## New targets have been established for 809-1 and 811-1

| LINER | Target | N Rows |
|---|---|---|
| | Target | 1 |
| 1Y3555 | | 131 |
| 1Y3555 | Target | 46 |
| 1Y3998 | | 43 |
| 1Y702 | | 0 |
| 2W600 | | 22 |
| 2W600 | Target | 10 |
| 7W355 | | 45 |
| 7W355 | Target | 3 |
| | Sum | 301 |

| | Liner target | N Rows |
|---|---|---|
| 1 | Target | 60 |
| 2 | 1Y3555 | 120 |
| 3 | 1Y3998 | 43 |
| 4 | | 78 |

N=223

Other liners