The application of locally developed pavement temperature prediction algorithms in Performance Grade (PG) binder selection

Prepared for SATC 2007

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Presentation structure

- Temperature susceptibility of HMA
- Pavement temperature prediction equations,
- Validation of prediction models,
- Performance Grade (PG) binder specification,
- Binder selection using CSIR ThermalPADS,
- Future direction.

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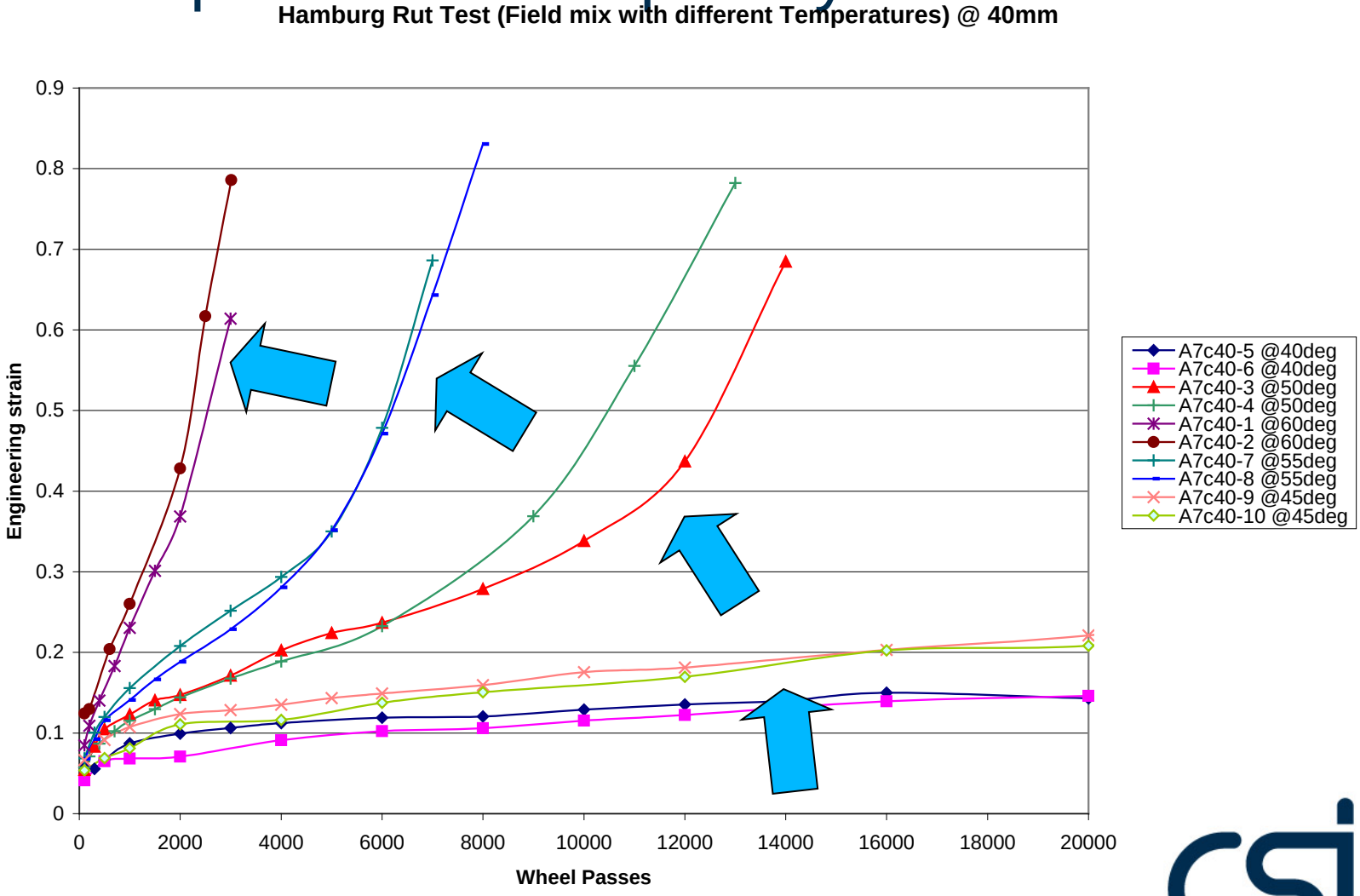
Temperature susceptibility of HMA



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Pavement temperature prediction

- Maximum daily surface temperature
- Qs + Qa - Qc - Qk - Qr = 0
- Qs = Energy absorbed at the asphalt surface from direct solar radiation.
- Qa = Energy absorbed at the asphalt surface from atmospheric radiation.
- Qc = Energy transferred from the asphalt surface to the surrounding atmosphere by convection.
- Qk = Energy transferred from the asphalt surface into the asphalt layer.
- Qr = Radiation energy emitted from the asphalt surface.

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Pavement temperature prediction

- Maximum surface temperature SUPERPAVE (Huber)

$$T_{s(max)} = T_{air(max)} - 0.00618 \times latitude^2 + 0.2289 \times latitude + 24.4$$

- Maximum surface temperature Vilioen

$$T_{s(max)} = T_{air(max)} + 24.5(\cos Z_n)^2 \times C$$

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Pavement temperature prediction

- Minimum surface temperature SUPERPAVE

$$T_{s(min)} = 0.859T_{air(min)} + 1.7$$

- Minimum surface temperature Viljoen

$$T_{s(min)} = 0.89T_{air(min)} + 5.2$$

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Pavement temperature prediction

- Maximum temperature at depth
  - SUPERPAVE

$$T_{d(max)} = \left(T_{s(max)} + 17.8\right)\left(1 - 2.48 \times 10^{-3} d + 1.085 \times 10^{-5} d^2 - 2.441 \times 10^{-8} d^3\right) - 17.8$$

  - Viljoen

$$T_{d(max)} = T_{s(max)} \left(1 - 4.237 \times 10^{-3} d + 2.95 \times 10^{-5} d^2 - 8.53 \times 10^{-8} d^3\right)$$

- Minimum temperature at depth
  - SUPERPAVE

$$T_{d(min)} = T_{s(min)} + 5.1 \times 10^{-2} d - 6.3 \times 10^{-5} d^2$$

  - Viljoen

$$T_{d(min)} = T_{s(min)} + 3.7 \times 10^{-2} d - 6.29 \times 10^{-5} d^2$$

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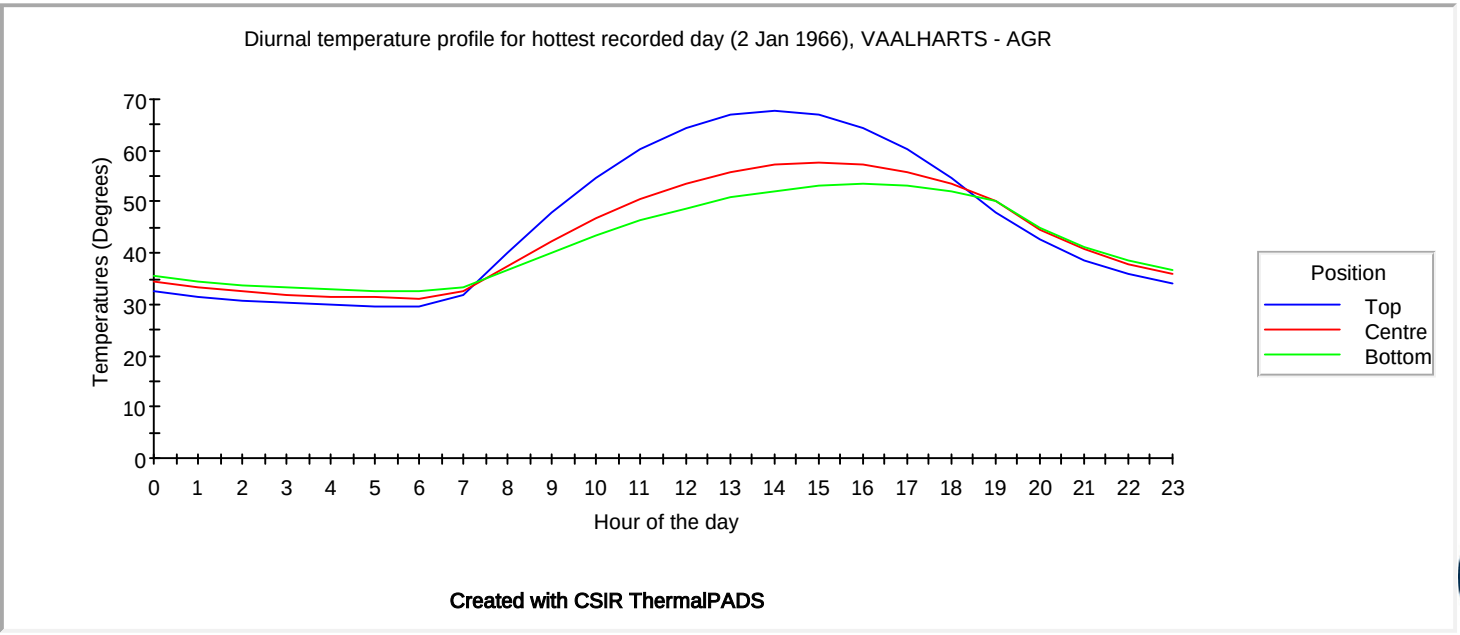
Pavement temperature prediction

- Diurnal temperature profile (Viljoen only)

$$T_{d(t)} = T_{d(min)} + \left[T_{d(max)} - T_{d(min)}\right] \sin\left[\pi \frac{(t - t_r - \beta)}{DL + 2(\alpha - \beta)}\right]$$



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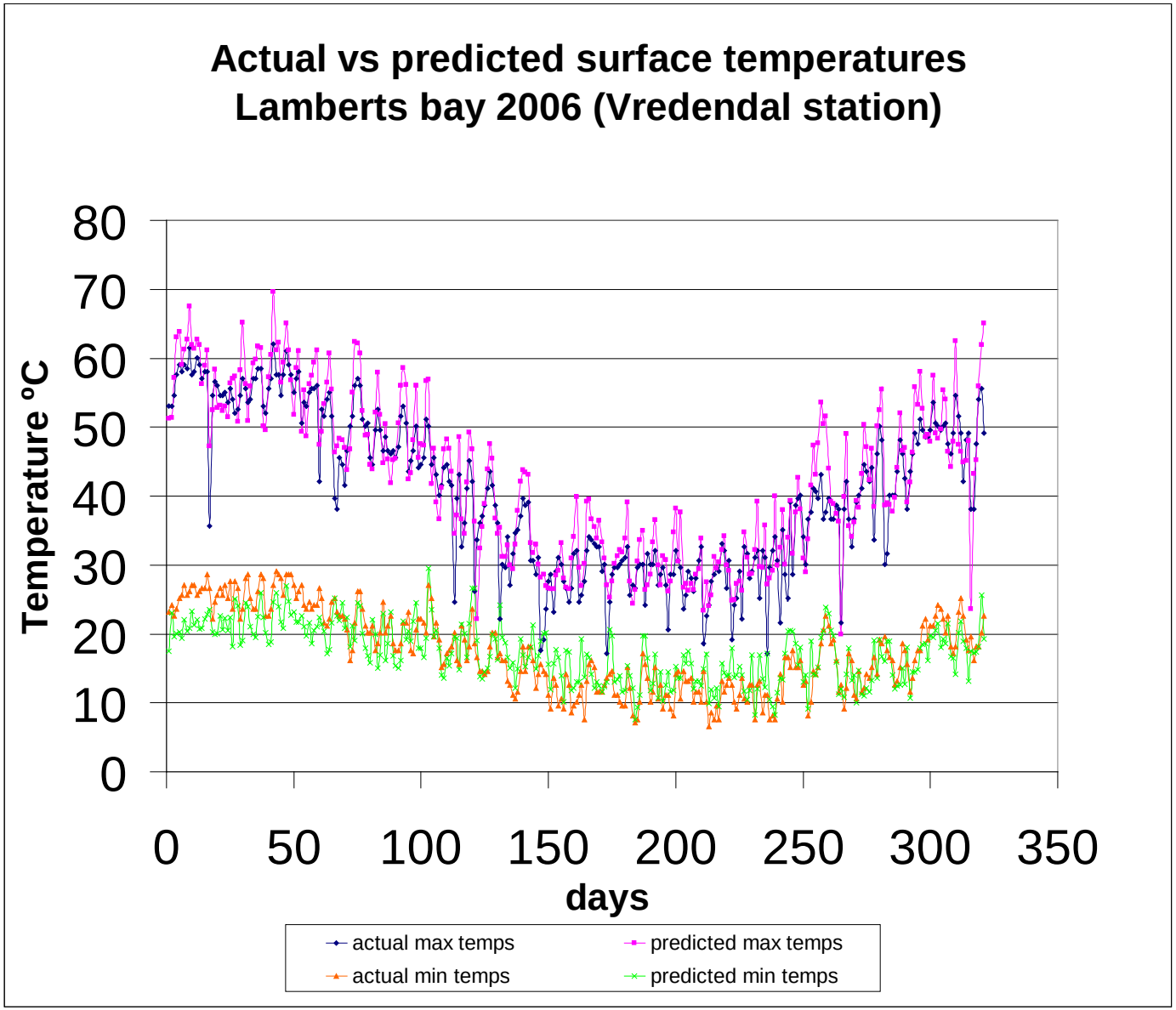
Validation of prediction models



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Validation prediction models

Maximum surface temperature (actual - predicted)

Location	Number of days data	Viljoen equation		Superpave	
		Mean error [ºC]	Standard deviation of error [ºC]	Mean error [ºC]	Standard deviation of error [ºC]
Cullinan (R238)	93	1.72	2.59	-4.32	-3.29
Vereniging (P234/1)	92	0.31	2.48	-2.03	2.83
Cape Town (N7)	332	-3.40	2.92	1.82	6.66
Lamberts Bay (R365)	320	-2.05	3.68	3.46	7.11

Minimum surface temperature (actual - predicted)

Location	Number of days data	Viljoen equation		Superpave	
		Mean error [ºC]	Standard deviation of error [ºC]	Mean error [ºC]	Standard deviation of error [ºC]
Cullinan (R238)	93	-2.73	2.23	2.67	2.13
Vereniging (P234/1)	92	1.01	2.44	5.39	2.20
Cape Town (N7)	332	-2.80	2.85	3.23	2.28
Lamberts Bay (R365)	320	0.19	3.17	6.17	3.37

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Performance Grade (PG) binder specification

- Applicable to modified and unmodified bituminous binders,
- Based on the stiffness of the aged binder,
- Takes into account traffic load and environmental condition,
- Specification for high and low temperature
  - PG x-y with x is high temperature y is low temperature
- Spec based on 100 km/hr and 10^7 E80s max.

SA bitumen (source SABITA)

Pen grade	40/50	60/70	80/100	150/200
Refinery I	X	PG 64-16	PG 58-22	X
Refinery II	PG 64-16	PG58-22	PG 58-22	X
Refinery III	PG 64-16	PG64-22	PG 58-16	PG 52-22
Refinery IV	PG 70-20	PG 64-16	PG 58-22	PG 52-22

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Binder selection using ThermalPADS

- Details on CSIR ThermalPADS
  - Based on Viljoen asphalt pavement temperature prediction equations,
  - Uses daily maximum and minimum air temperature to calculate:
    - Maximum and minimum surface temperature,
    - Temperature at depth,
    - Diurnal temperature profile
  - Currently contains weather data from 65 SA weather stations
  - Can be used to select Performance Grade (PG) binder,
  - Software available from www.prac.co.za

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Binder selection using ThermalPADS

- Case I
  - Freeway near Darling in Western Cape
  - Lattitude -33.3º
  - Expected E80s on HMA overlay: 12E06
  - No intersections
  - Required design reliability: high
- Case II
  - Provincial road in Midrand (Gauteng)
  - Lattitude -26.0º
  - Expected E80s on HMA overlay: 6E06
  - Intersections
  - Required design reliability: medium

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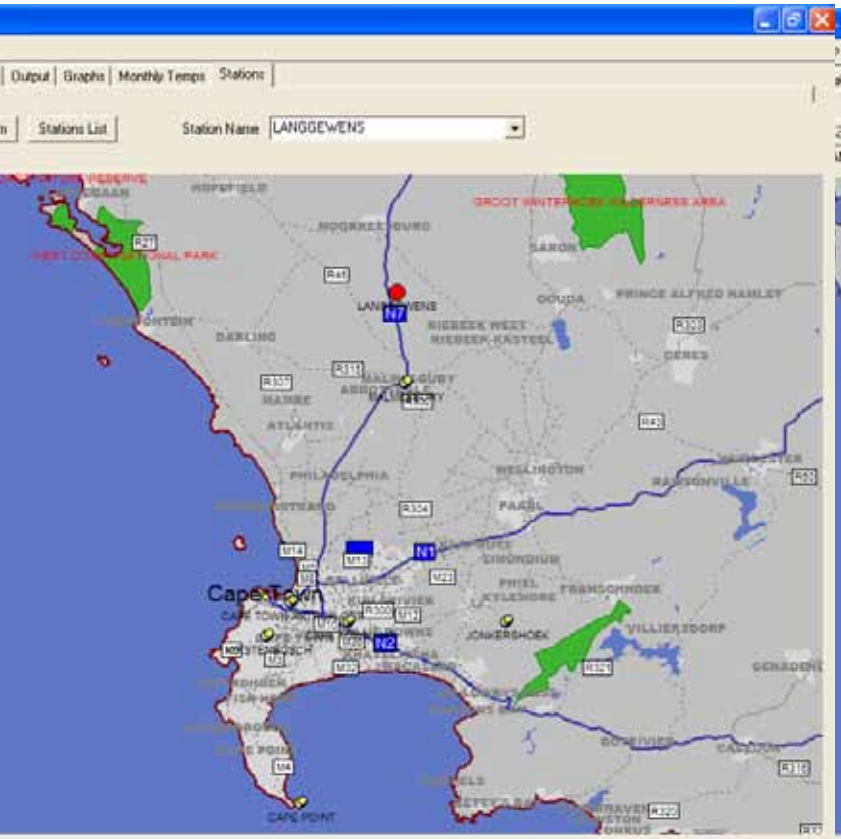
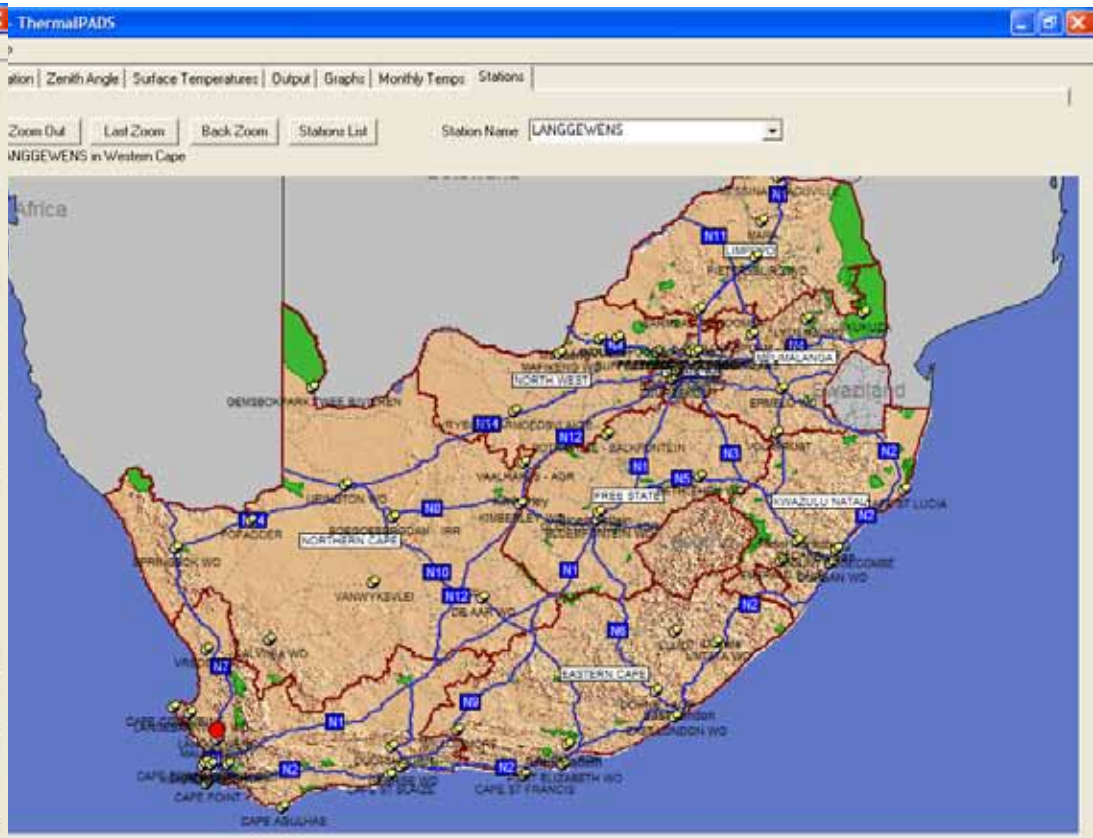
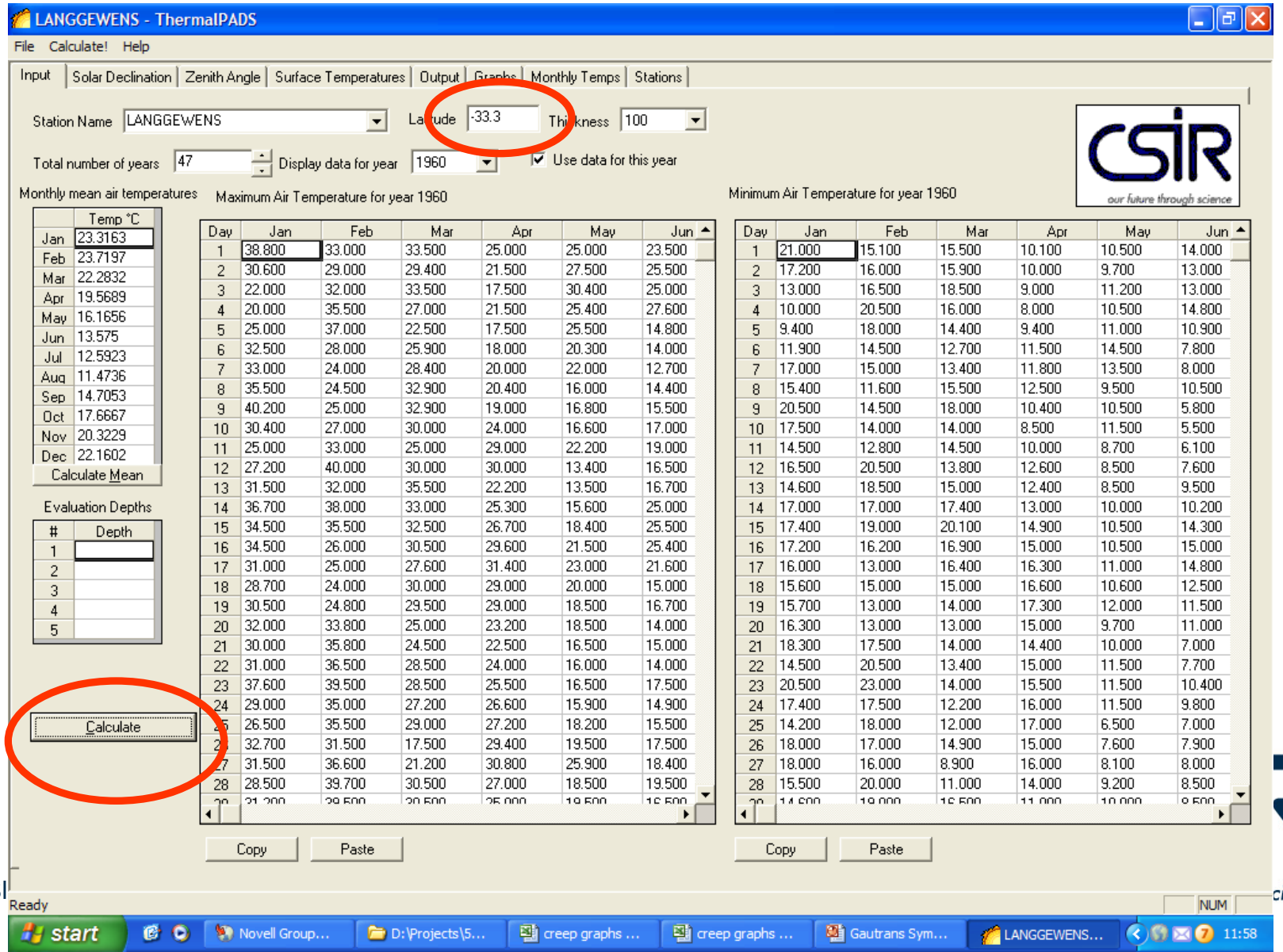
Step 1: select nearby weather station

- Confirm climate on site is similar to weather station,
- Stations selected: Langgewens (WC) & Irene (Gauteng)

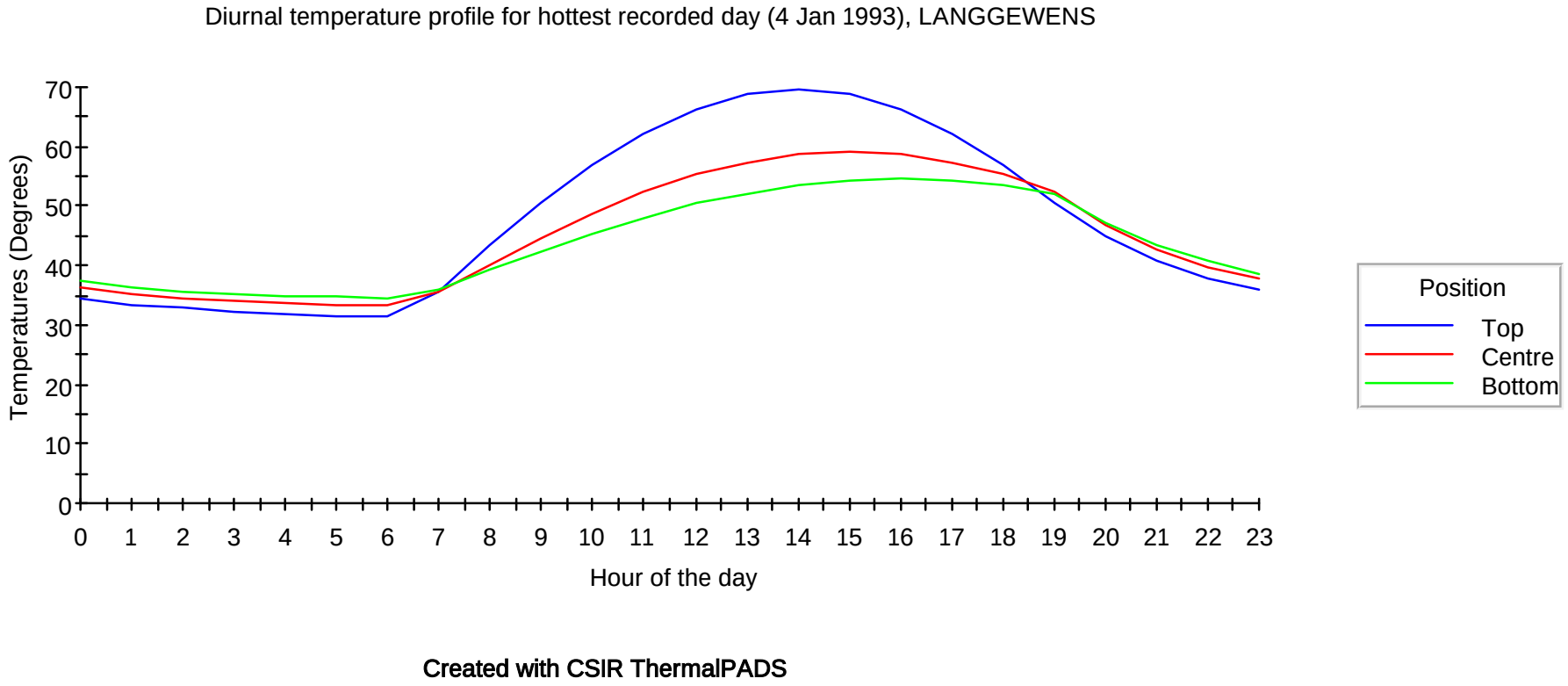




Step 2: Input latitude of road



Typical output: Diurnal temperature profile



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Step 3: Interpret temperature statistics

LANGGEWENS - ThermalPADS

File Calculate! Help

Input | Solar Declination | Zenith Angle | Surface Temperatures | Output | Graphs | Monthly Temps | Stations

Extreme surface temperatures (days per year)

Year	Average	Year 1960	Year 1961	Year 1962	Year 1963	Year 1964	Year 1965	Year 1966	Year 1967	Year 1968	Year 1969	Year 1970	Year 1971	Year 1972	Ye
>40°C	184	193	177	179	196	181	177	189	190	174	180	177	178	196	
>45°C	148	156	146	149	162	139	139	149	156	145	144	144	150	156	
>50°C	96	107	100	91	116	85	70	102	105	81	94	84	90	105	
>55°C	55	75	60	57	80	56	33	64	75	45	49	41	52	63	
>60°C	16	26	17	15	20	17	12	15	21	8	11	12	17	19	
>65°C	1	3	0	1	4	0	2	1	1	0	0	0	0	5	
<5°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<0°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	
<-5°C	0	0	0	0	0	0	0	0	0	0	0	0	0	0	

	Mean	Standard deviation	98% Percentile
Hottest	55.83	1.74	59.31
Coldest	9.01	1.23	6.55

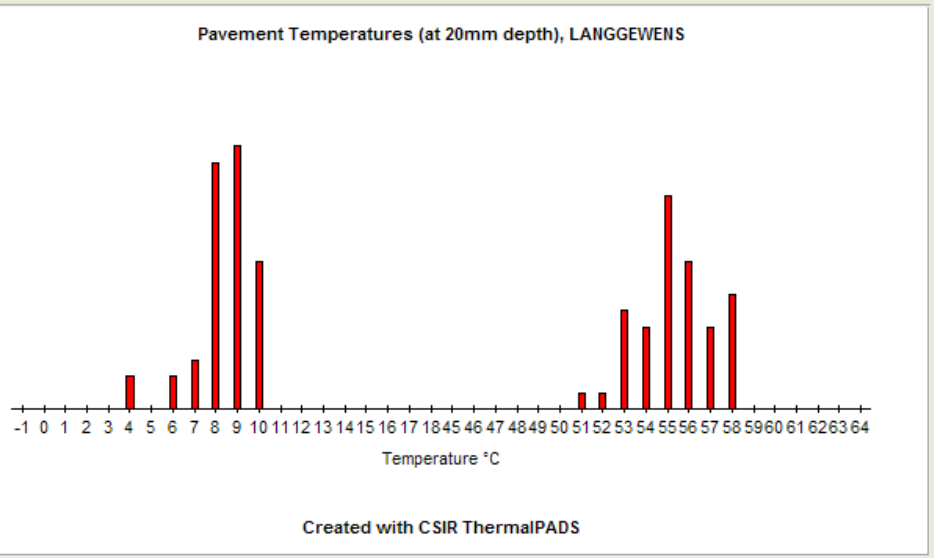
Print Graph | Copy Graph | Plot: PavementTemperatures

Extreme pavement temperatures (at 20mm depth) for data set

	Temp	Day	Month	Year
Hottest 7day	58.8	17	Dec	1979
Hottest day	64.4	4	Jan	1993
Coldest day	4.9	1	Dec	1977

Extreme pavement temperatures (at 20mm depth) per year

	Temp	Day	Month	Year
Hottest 7day	56.7	9	Dec	1960
Hottest day	63.3	13	Dec	1960
Coldest day	8.6	19	Jul	1960
Hottest 7day	54.5	20	Jan	1961
Hottest day	60.0	24	Jan	1961
Coldest day	9.3	6	Aug	1961
Hottest 7day	54.0	1	Jan	1962
Hottest day	61.7	2	Jan	1962
Coldest day	8.4	14	Jun	1962
Hottest 7day	58.4	13	Jan	1963



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Step 4: Determine PG grade

Road section	Darling	Midrand
Seven day average maximum temperature (20 mm depth) [Median / 98th percentily value]	55.8 ° C / 59.31 ° C	52.3 ° C / 56.1 ° C
Minimum surface temperature [Median / 98th percentily value]	9.0 ° C / 6.6 ° C	4.1 ° C / -2.1 ° C
Required design reliability	High (Use 98th percentile)	Medium
Expected traffic [E80s]	> 10E06 (increase PG)	< 10 E06
Slow moving or stationary loads (intersections)	no	Yes (increase PG)
Selected PG grade	PG 64 - 16 or PG 70 - 20	PG 58 - 16

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Available PG binders in SA (source: SABITA)

Pen grade	40/50	60/70	80/100	150/200
Refinery I	X	PG 64-16	PG 58-22	X
Refinery II	PG 64-16	PG58-22	PG 58-22	X
Refinery III	PG 64-16	PG64-22	PG 58-16	PG 52-22
Refinery IV	PG 70-20	PG 64-16	PG 58-22	PG 52-22

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Conclusions

- The temperature algorithms developed by Viljoen (2001) provide an acceptable prediction of extreme surface temperatures of four LTPP sections in Gauteng and the Western Cape.
- The model yields acceptable results to start implementing and validating PG binder selection in South Africa

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Future direction

- Further validation required for outlying areas,
- Increase the number of weather stations from 65 to 500+,
- Link temperature prediction to HMA stiffness and rutting models,
- Take into account the effect of binder ageing,
- Include temperature prediction algorithms for other materials (concrete pavements, granular base layers).

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End, thank you!