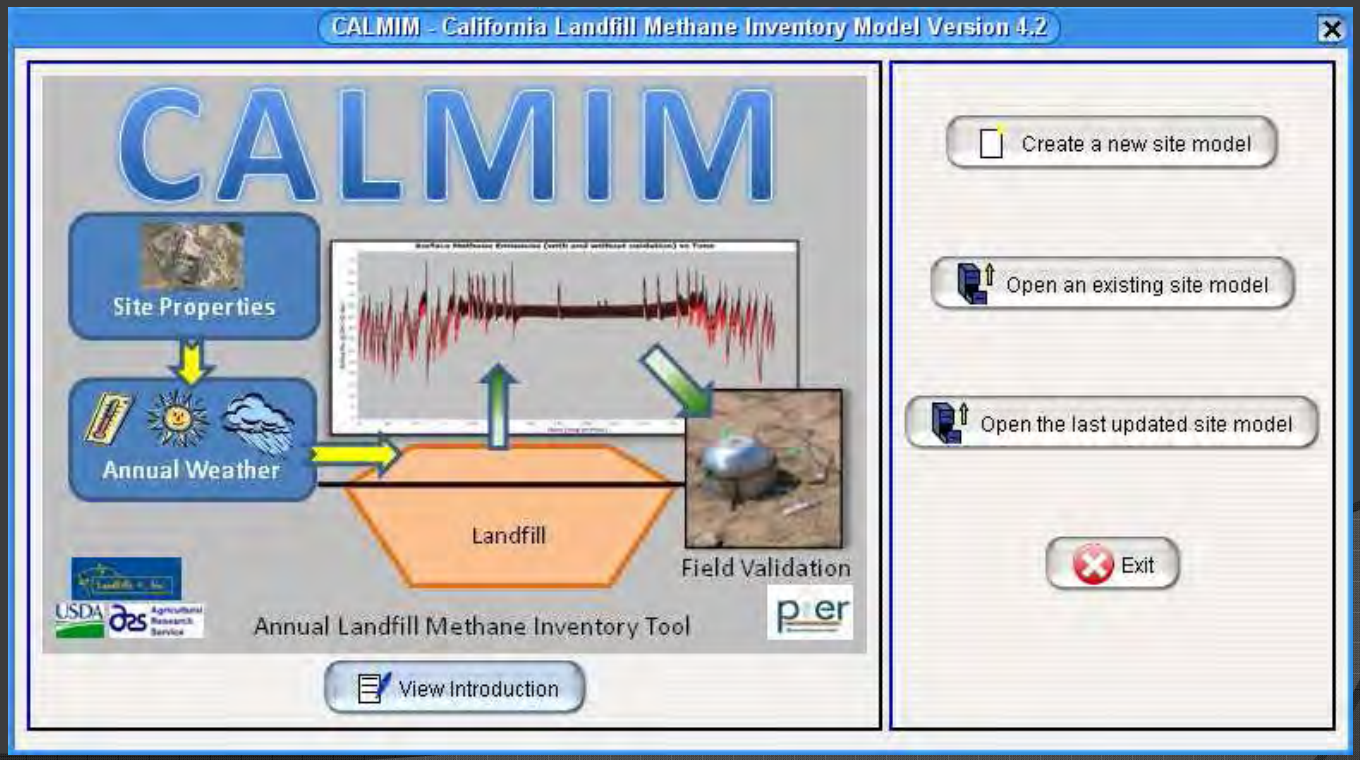
Model Description

Model Overview

- Written in Java
- Open Source / cross platform
  - 71 source files
- After encountering memory issues:
  - Switched to a pre-compiled version of the program (Excelsior JET package)
- 4 other programmers:
  - Roger Schlachter, Chris Schmitt, Andy Kuhn, and Andy Korth
- Assistance from several JAVA library developers

Model Description

- Overall Data Requirements:
  - Site Properties
  - Cover Properties



1. Site Properties

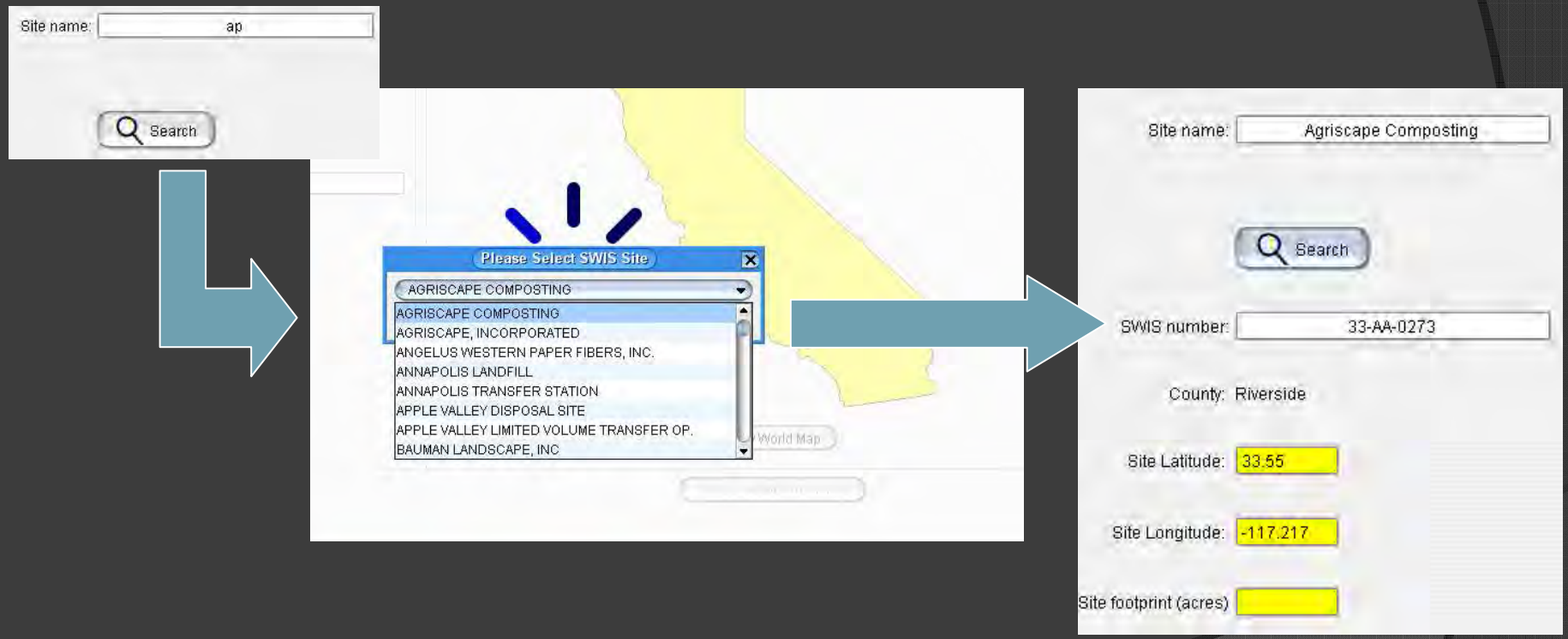
- Latitude
- Longitude

  } Also available through SWIS database

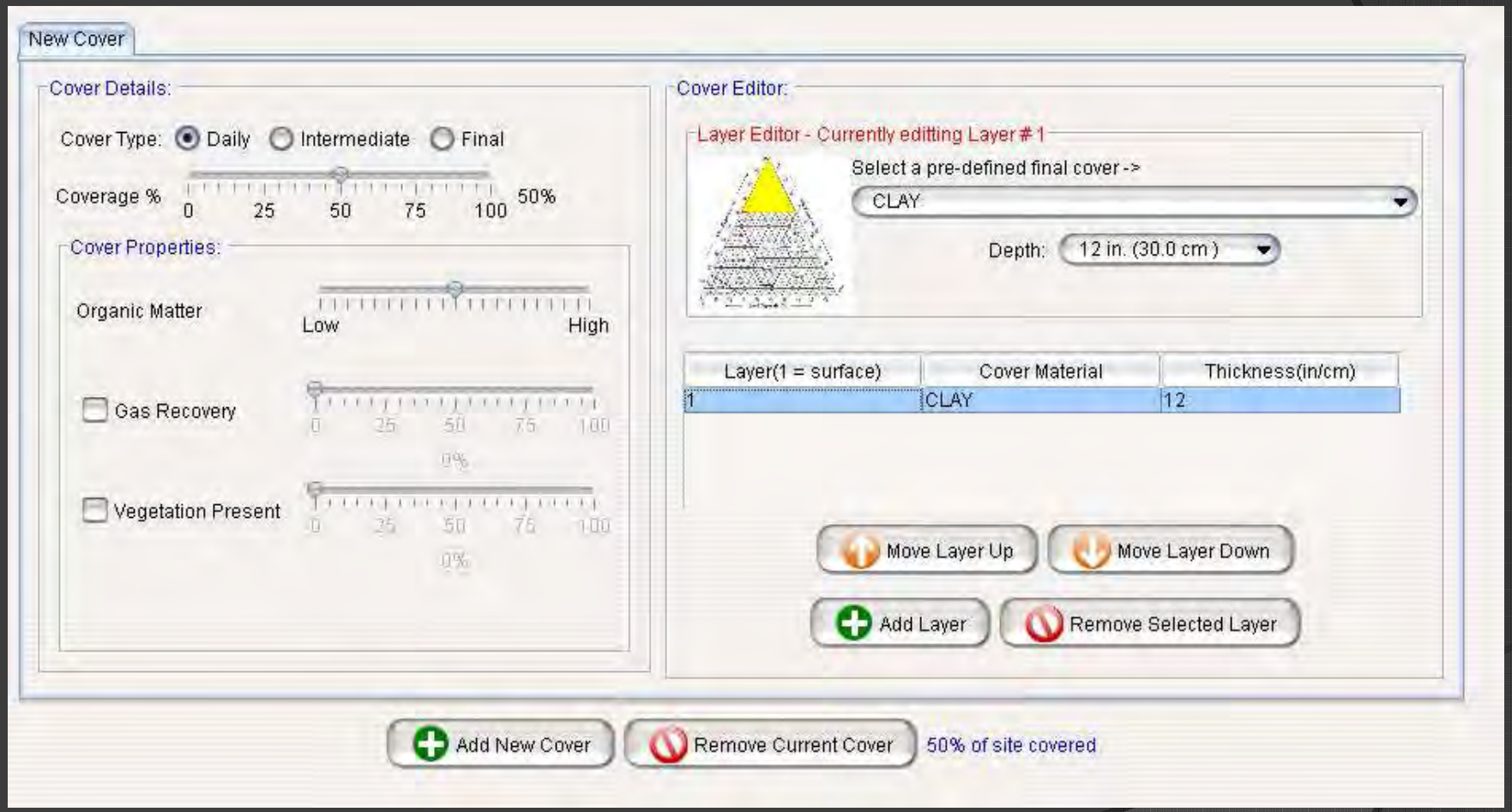
  - Needed for climate simulation
- Size of landfill – total waste footprint (acres)

SWIS Search

- SWIS database



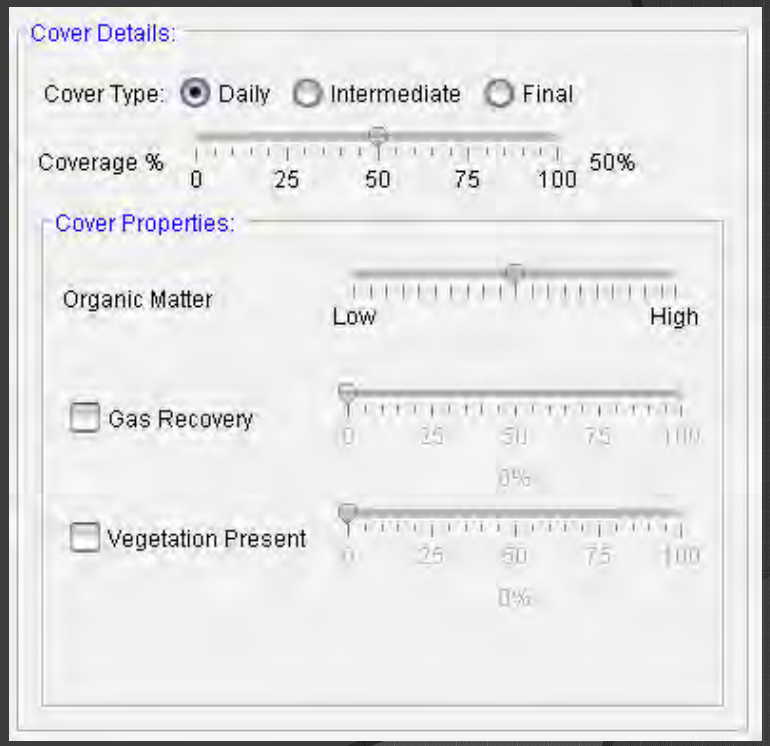
2. Cover Properties Panel



- Up to 10 different covers allowed in each model run

Cover Panel: Cover Details

- Cover type:
  - Daily, Intermediate, or Final
- Coverage %
  - Area coverage at the site for this particular cover type

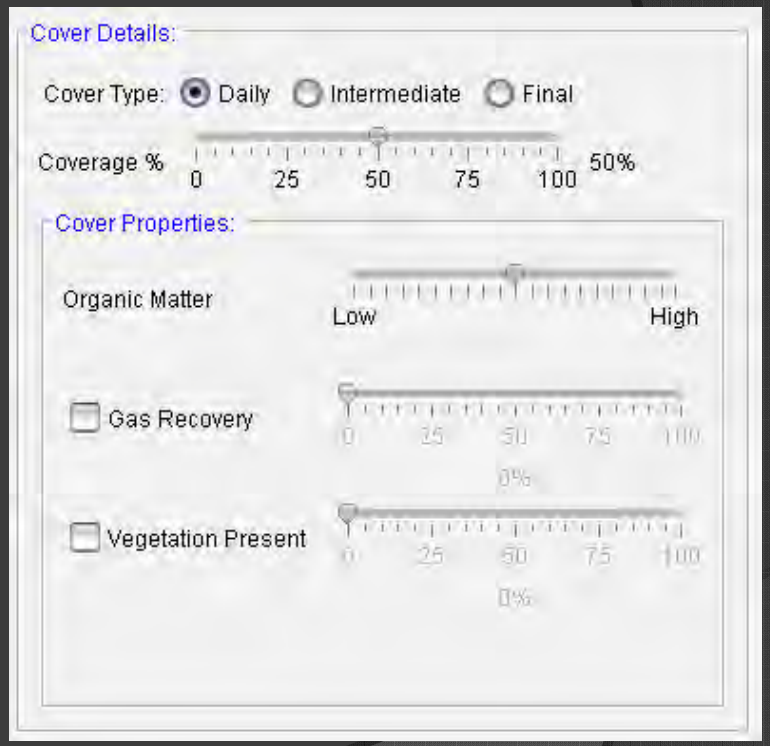


Default Boundary Conditions

Cover Type	Lower Temperature Boundary Condition (°C)	Lower Methane Boundary Condition (% vol)	Lower Oxygen Boundary Condition (% vol)
Daily	25	1(*)	5
Intermediate	35	45	1
Final	40	55	0

* Field data actually significantly lower (3000 ppm Marina and 3 ppm Scholl)

Cover Panel: Cover Details



Cover Properties scroll bars

- Organic Matter content
- Gas Recovery
- Vegetation Presence

Organic Matter Percentage

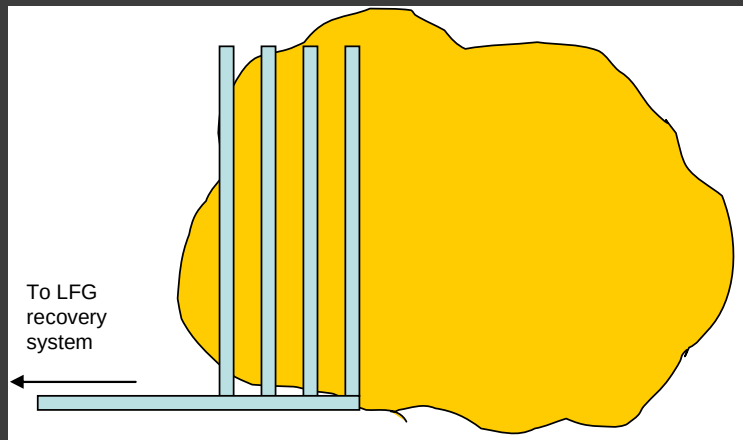
- Impacts hydraulic conductivity and water holding capacity
  (Benjamin et al., 2008)

- Low to High corresponds to
  0 to 5%

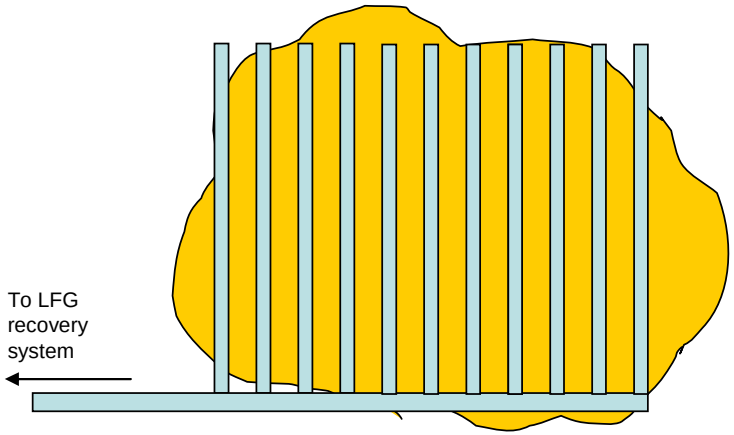
Cover Panel: Gas Recovery

- Gas Recovery Percentage
  - This is NOT the recovery "efficiency"
  - Indicates the ***spatial coverage*** of the gas recovery system for that particular cover

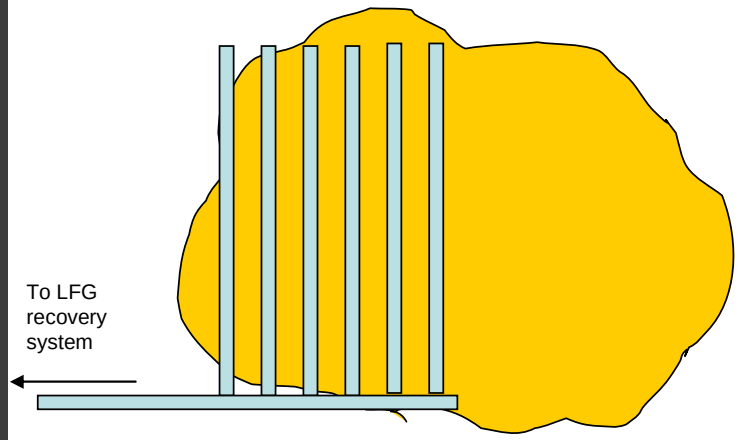
Cover Panel: Gas Recovery Coverage %



33% Gas Recovery Coverage



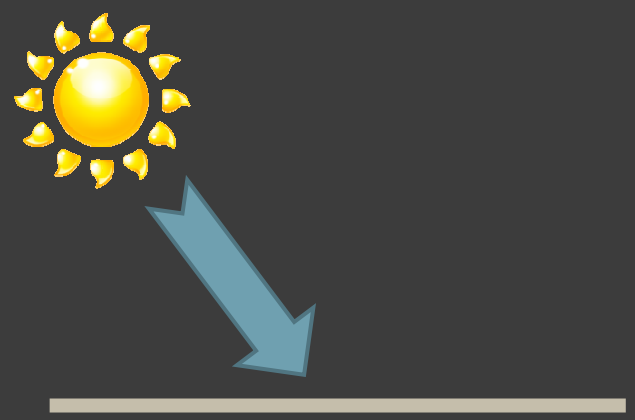
100% Gas Recovery Coverage

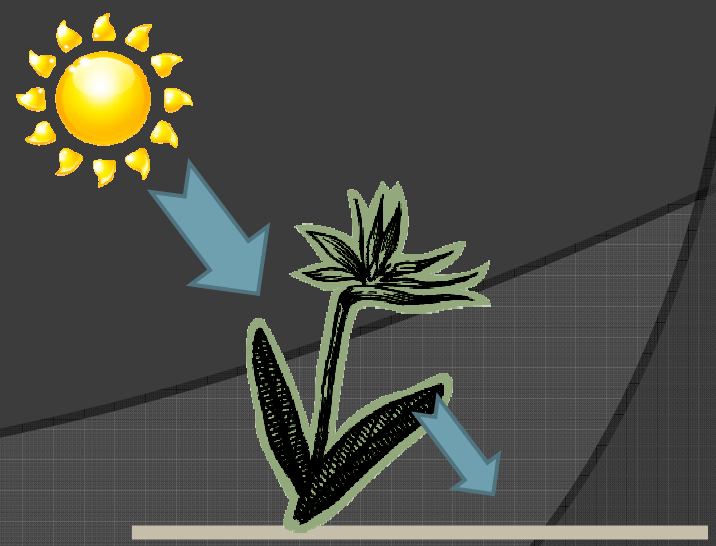


50% Gas Recovery Coverage

Vegetation Percentage

- Estimated on surface coverage of vegetation
- Main impact:
  - Decreases incident solar radiation to the soil surface
    - Reduces heating and soil surface evaporation





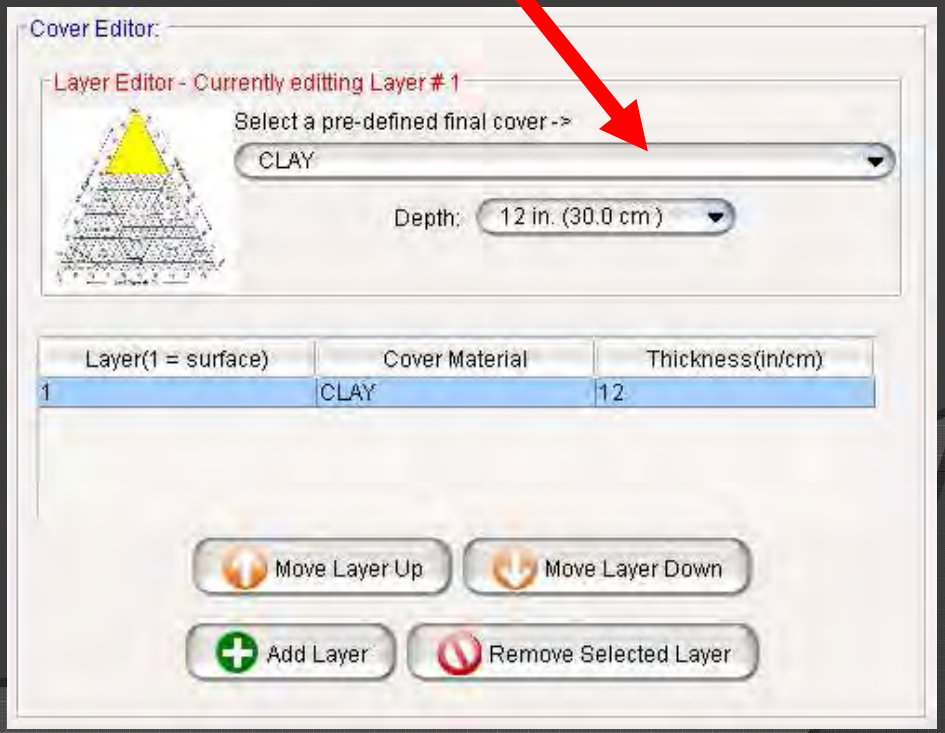
Cover Panel :
Custom Cover Editor

Cover Editor :

Once layer highlighted:

1. Edit layer material – 33 different materials

- 12 Textural soil types (USDA soil classifications)
  - SILTY CLAY, CLAY, SILTY CLAY LOAM, SILT, CLAY LOAM, SILTY LOAM, SANDY CLAY, LOAM, SANDY CLAY LOAM, SANDY LOAM, LOAMY SAND, SAND



Cover Editor :

Once layer highlighted:

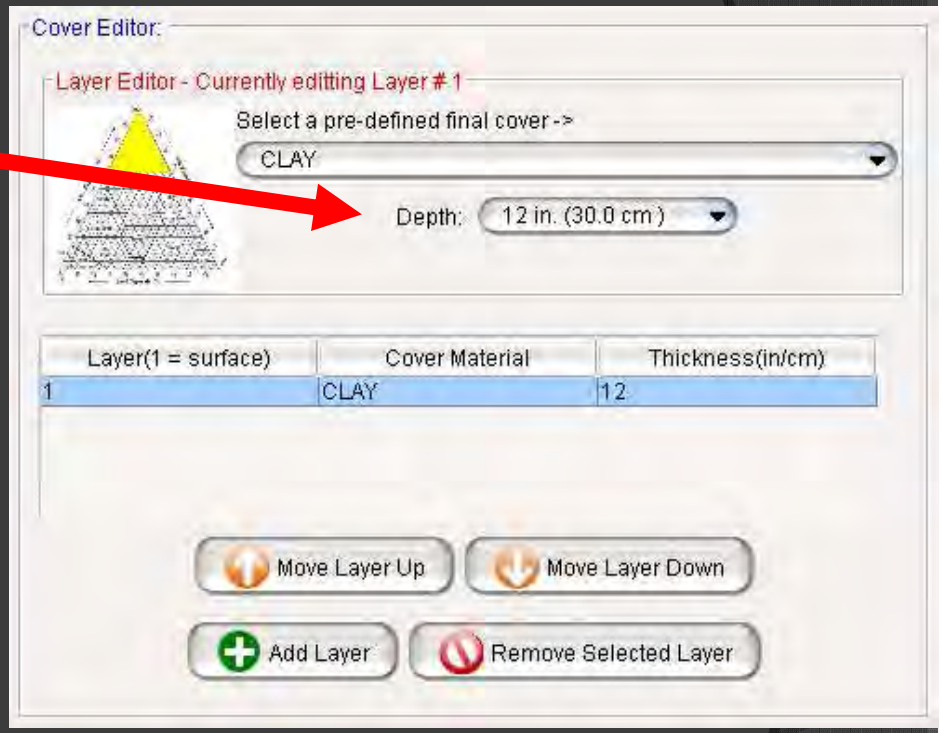
1. Edit layer material

- 12 Soil types (USDA soil classifications)
  - SILTY CLAY, CLAY, SILTY CLAY LOAM, SILT, CLAY SANDY CLAY, LOAM, SANDY CLAY LOAM, SANDY
- 21 Alternative Daily Covers and other materials
  - ADC Materials (e.g. tarps, foams, shredded tires, compost)
  - Other
    - Geomembranes (HDPE, LDPE, EDPM); Geotextiles
    - Rocks, Pebbles (pea gravel)
    - Contaminated soils
    - Foundry sands
    - Wood Chips

Cover Editor :

Once layer highlighted:

1. Edit layer material
2. Specify thickness of the materials
3. Layers arranged from top to bottom



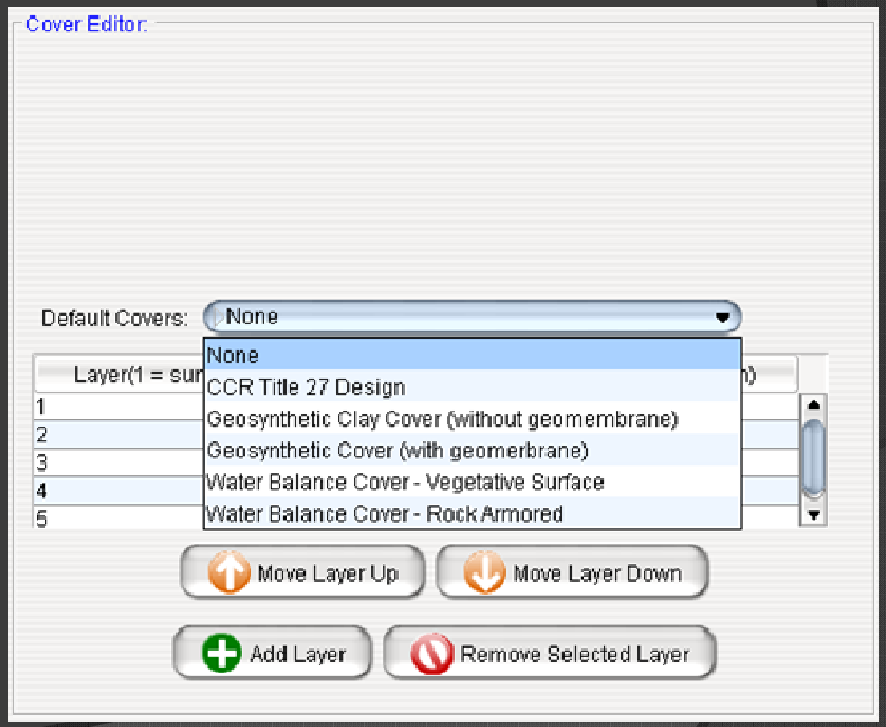
Cover Editor:

Once layer highlighted:

1. Edit layer material
2. Specify thickness of the materials
3. Layers arranged from top to bottom

Default Final Covers

- If the cover type of final cover is selected
- 5 default final cover designs are in a pull down combo box



Default final cover designs

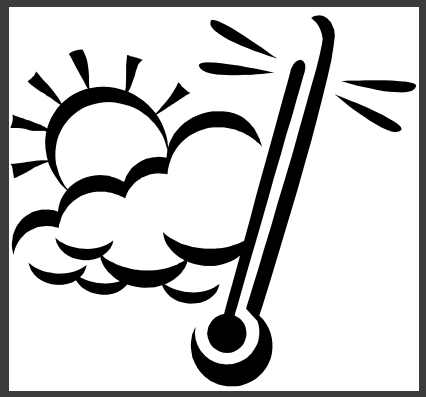
Layer	*CCR Title 27*	*Clay (without geomembrane)*	*Geosynthetic Cover (with geomembrane)*	*Water Balance (Vegetation Surface)*	*Water Balance (rock armored)*
1	Loam (12 inches)	Loam (12 inches)	Loam (12 inches)	Loam (12 inches)	Rocks/Boulders (6 inches)
2	Clay (12 inches)	Clay (40 inches)	HDPE geomembrane (1 inch*)	Silty Clay Loam (36 inches)	Loam (12 inches)
3	Silty Clay Loam (24 inches)	Silty Clay Loam (12 inches)	Silty Clay Loam (24 inches)		Silty Clay Loam (36 inches)

Vegetation	50%	50%	50%	50%	0%

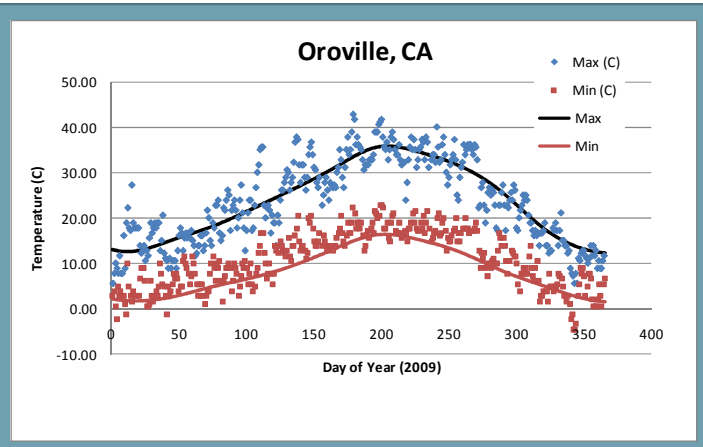
* Minimum layer size = 1 inch. HDPE is modeled as 40 micron HDPE with sand

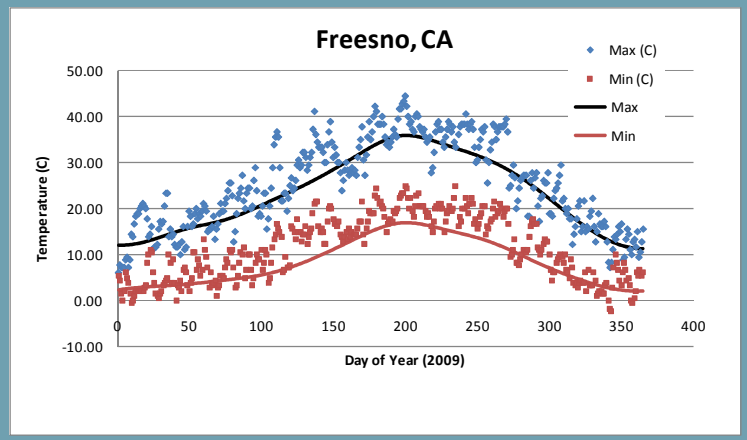
3. Simulated Weather

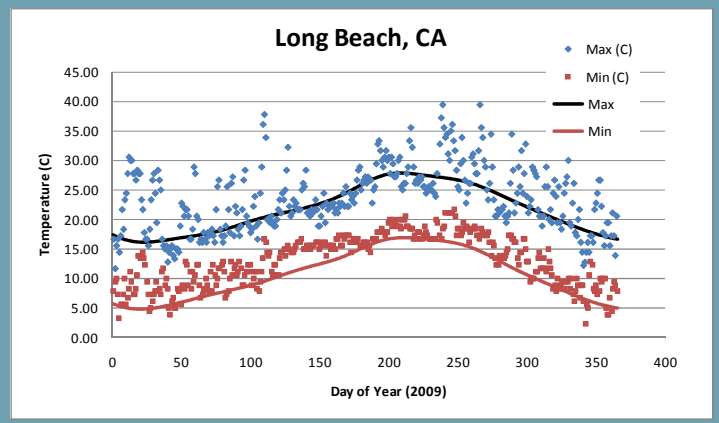
- CALMIM uses 3 previously validated simulation models
  - GlobalTempSIM
  - GlobalRainSIM
  - SolarCalc



Comparisons of Weather Simulator

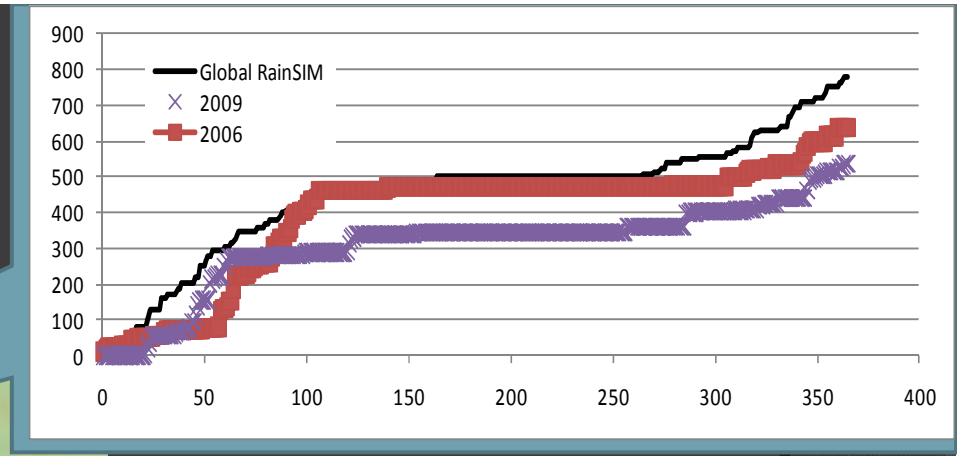


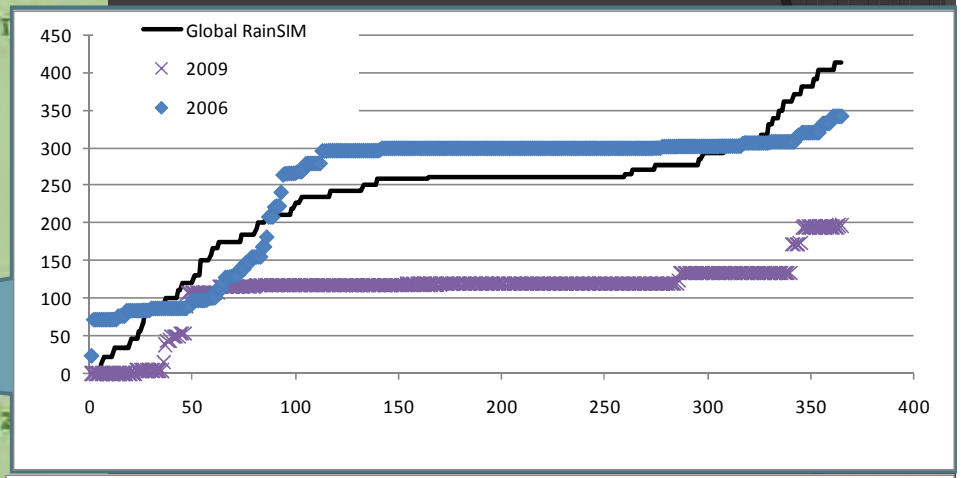


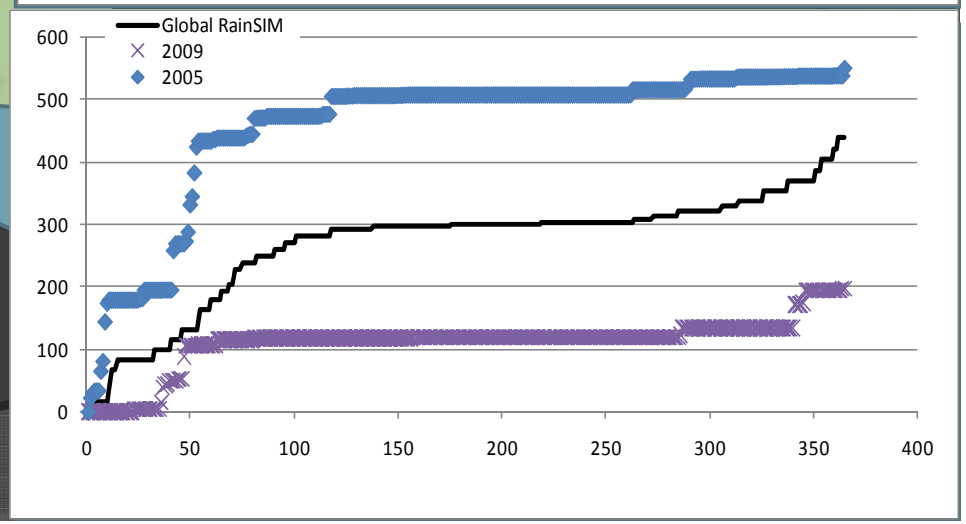


Weather Data from Weather Underground

Comparisons of Weather Simulator







Weather Data from Weather Underground

Soil Temperature and Moisture Model

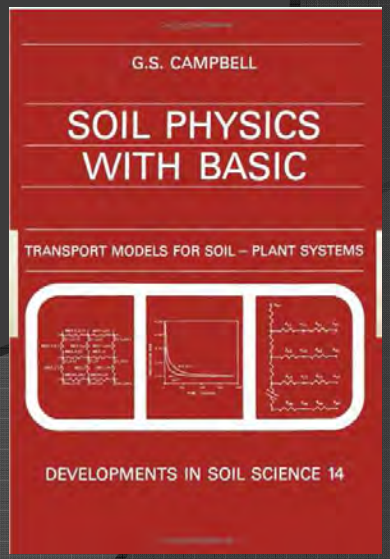
- Uses STM^2 model

(Spokas and Forcella, 2009)

- Some modifications:
  - Moisture boundary conditions –
    - Upper = evaporation/precipitation boundary
    - Lower = saturated or free drainage {saturated default condition}
  - Temperature boundary conditions –
    - Upper temperature boundary
      - Air temperature (simulated) or fixed temperature
    - Lower temperature boundary:
      - Function of cover type:
        - Daily : Average annual air temperature
        - Intermediate : 40 ^{o}C
        - Final : 45 ^{o}C

Gas Modeling

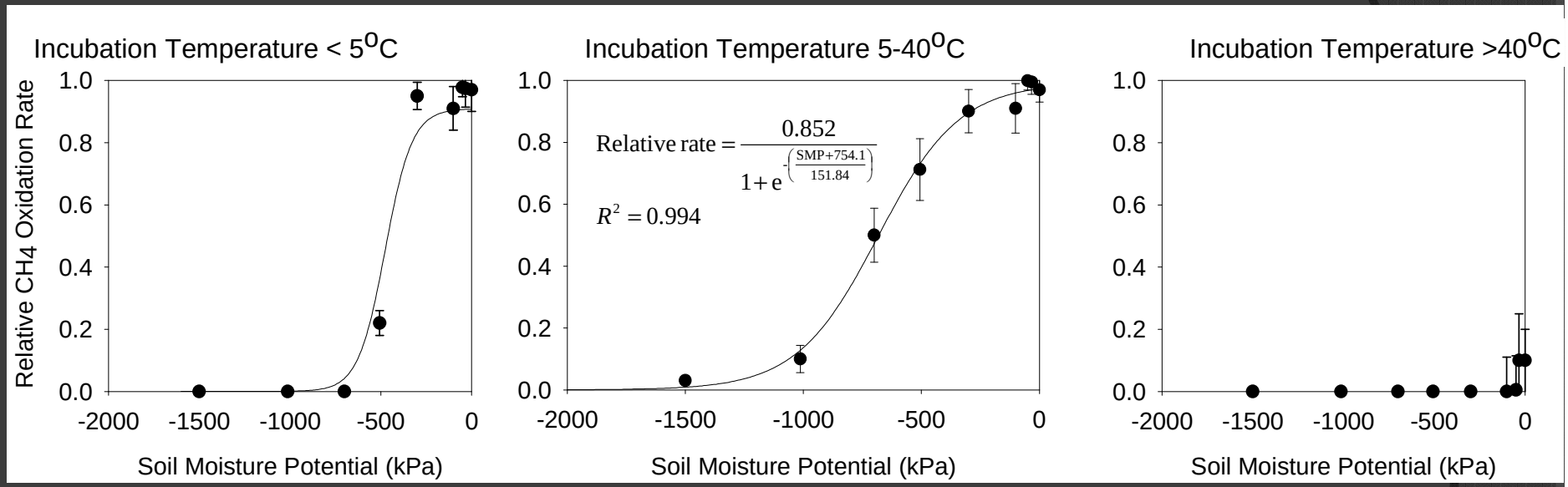
- Uses already developed 1-D gas transport model (Campbell, 1985)
  - Added empirical soil oxidation equations from laboratory testing for methanotrophic methane oxidation – specific for CA soils
  - 1-D Oxygen diffusion modeled
  - 1-D Methane diffusion modeled
    - With and without CH_4 oxidation

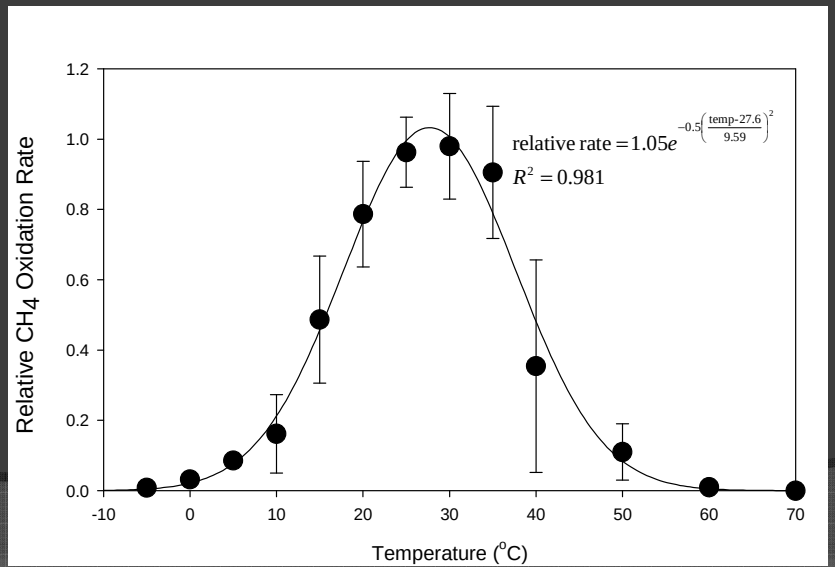


Supporting Laboratory Studies for Methane Oxidation Modeling

- A total of 2,112 soil incubations have been completed using Marina and Scholl Canyon cover soils
- Temperature range of 0-70 C and moisture range of -15 bar to zero soil moisture potential
- Incubators: Isothermal and diurnal fluctuations
- Detailed in published paper Spokas and Bogner, 2010.

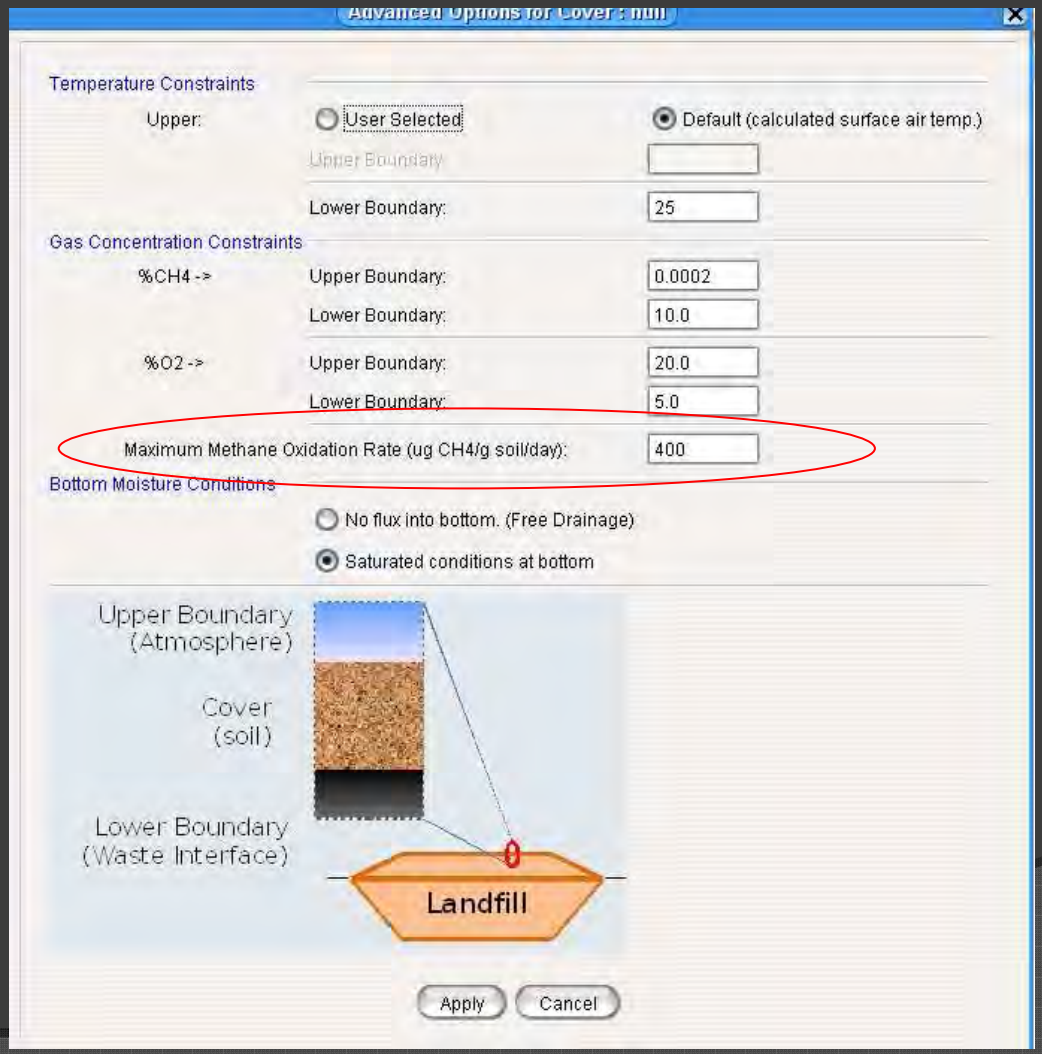
Laboratory Methane Oxidation Testing





- **The soil moisture potential for oxidation for 50% of activity for the two validation sites ≈ -600 kPa**
- **27 °C maximum from lab data**
- **400 ug CH_4 /g_{soil}/day average**

Advanced Settings

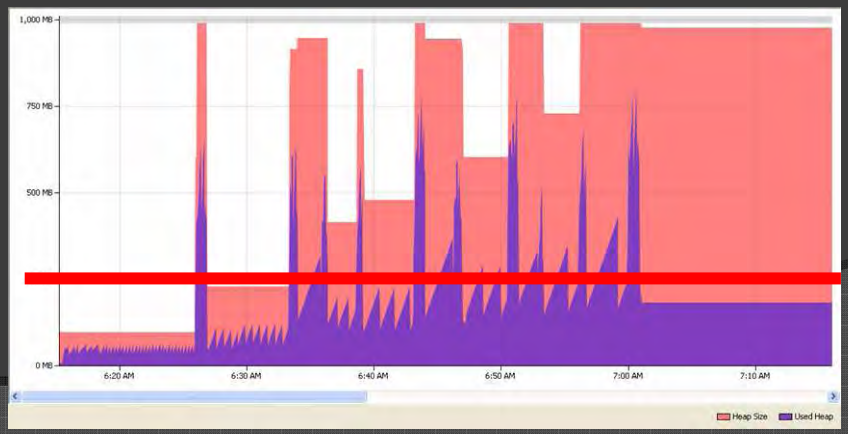


Beta Testing

- Initial testing conducted via USDA SharePoint server
  - Total # of registered users = 52
- Due to file compatibility issues (EXE files) and delay in getting individuals registered with SharePoint →moved to http://calmim.lmem.us
  - 55 downloads of versions up to 4.0
  - 83 downloads of version 4.2 (newest)

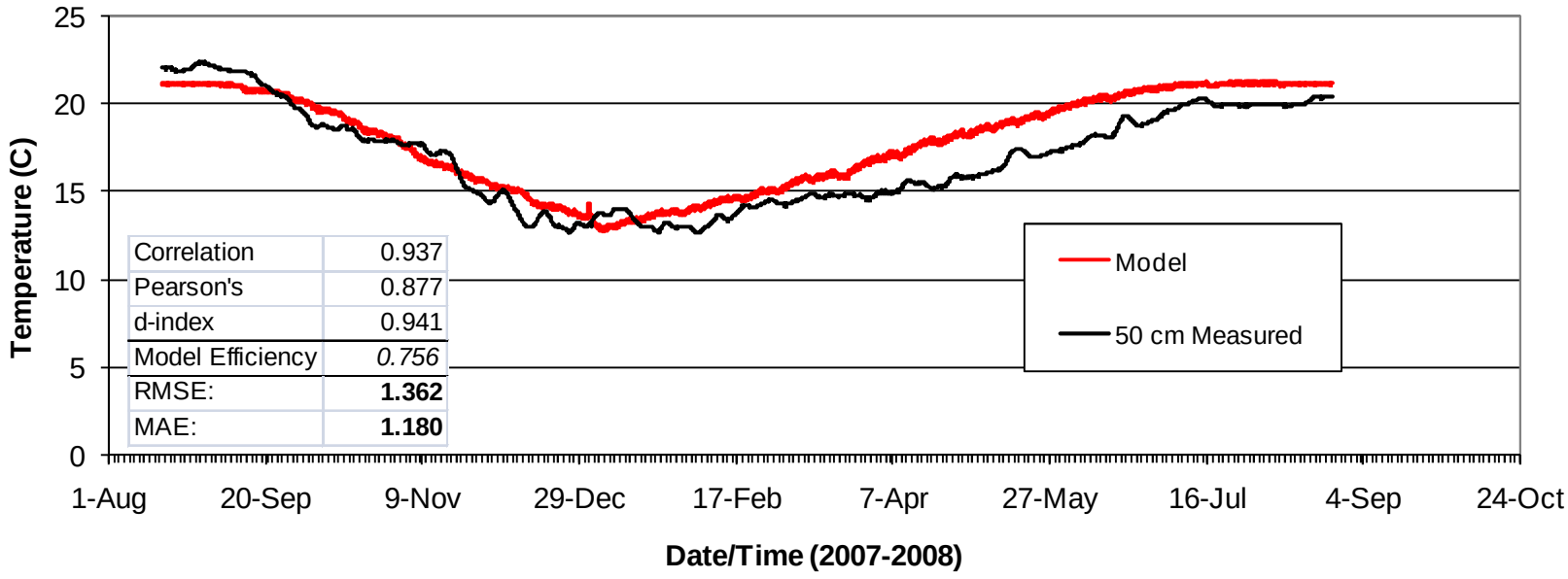
Beta Testing Results

- 10 users provided detailed comments
- Identified memory issues early on in the Beta testing
  - Java memory handling is poor; particularly for finite difference modeling
  - Reprogrammed calculation routines to avoid new variables; still occasional issues

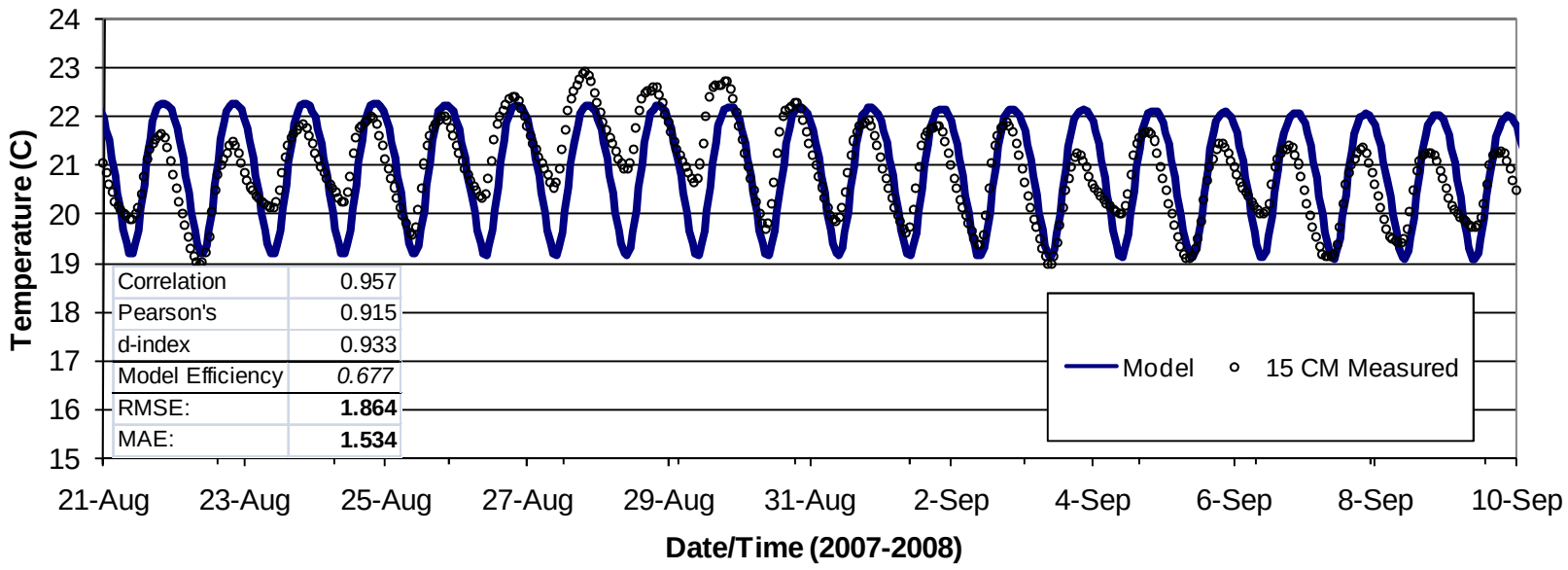


Field Validation

Marina Landfill Comparison
15 cm (intermediate cover) and 50 cm depth (final cover)



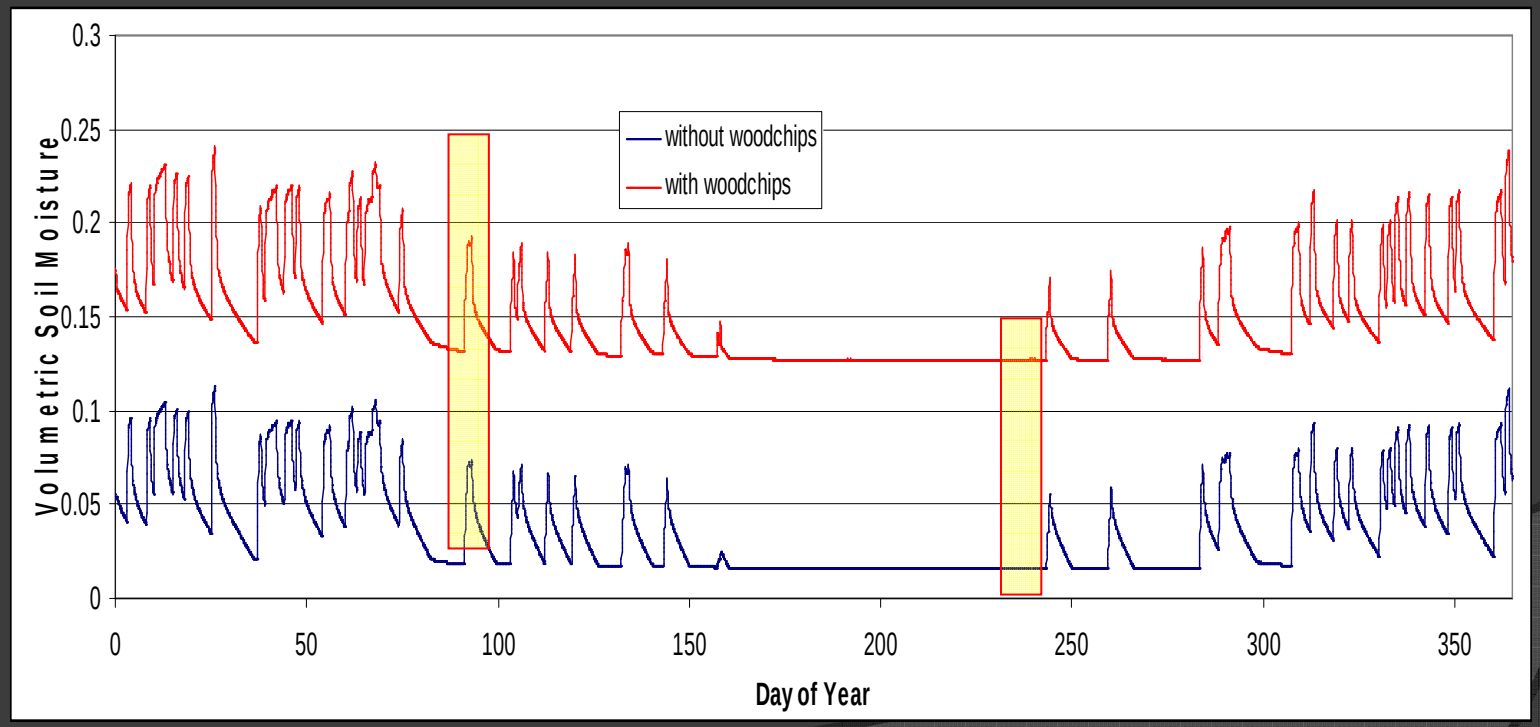
Correlation	0.937
Pearson's	0.877
d-index	0.941
Model Efficiency	*0.756*
RMSE:	**1.362**
MAE:	**1.180**



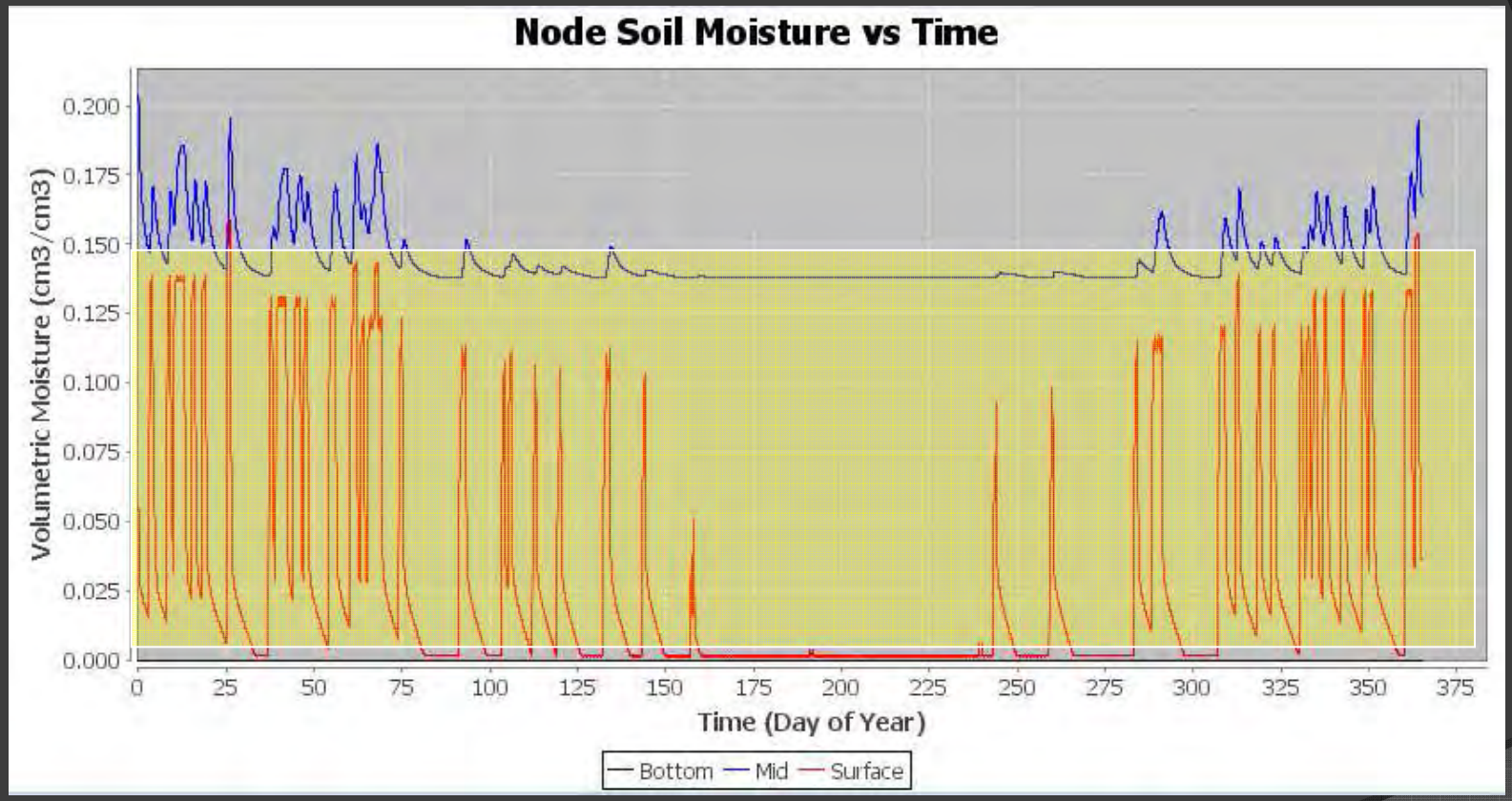
Correlation	0.957
Pearson's	0.915
d-index	0.933
Model Efficiency	*0.677*
RMSE:	**1.864**
MAE:	**1.534**

Soil Moisture - MIC

- Variable thickness of wood chips across area
- Reduces evaporation losses and increase soil moisture (0-8” thickness)
- Model with 2” wood chips



Soil Moisture: MDC

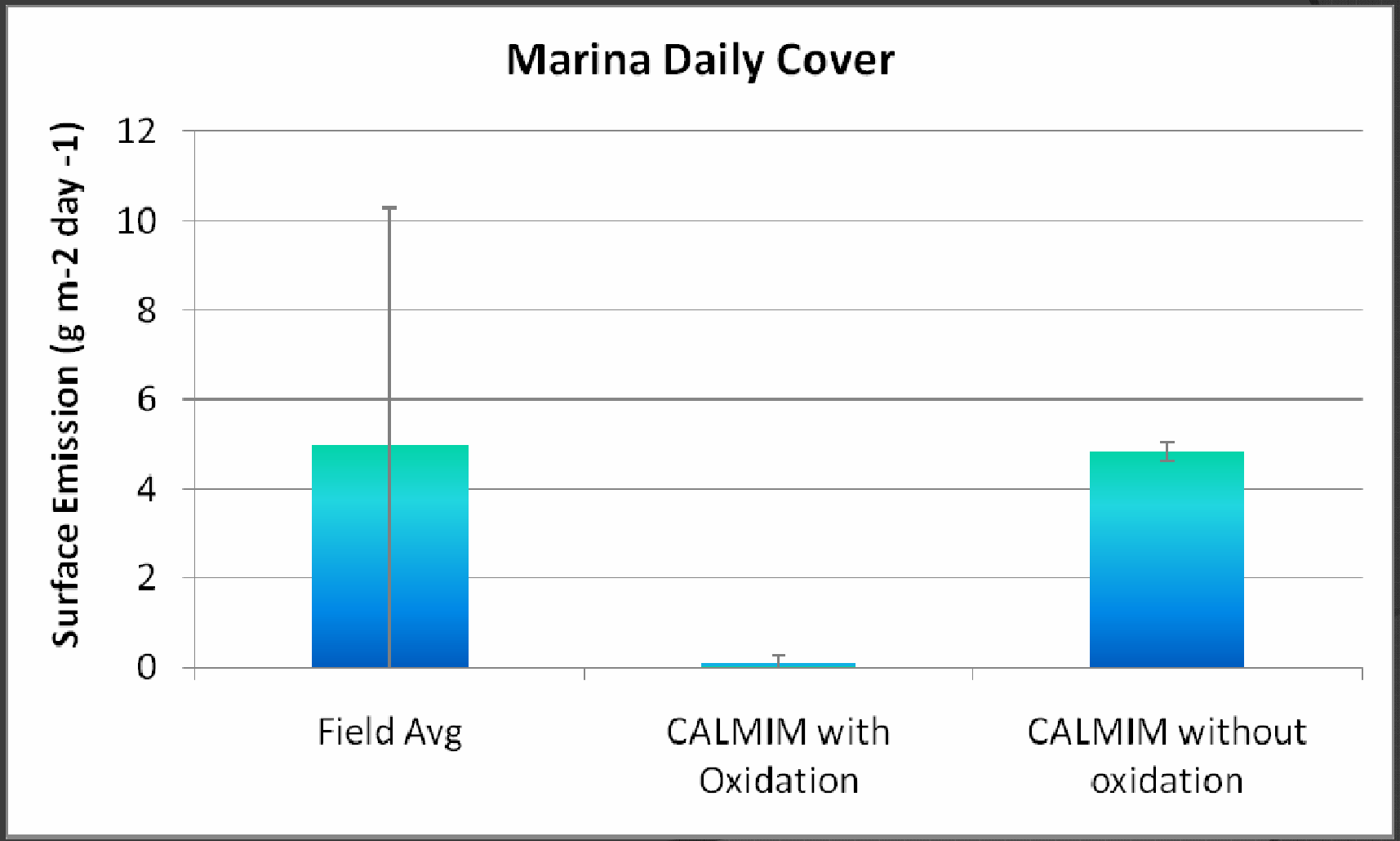


Marina Daily Cover Comparisons

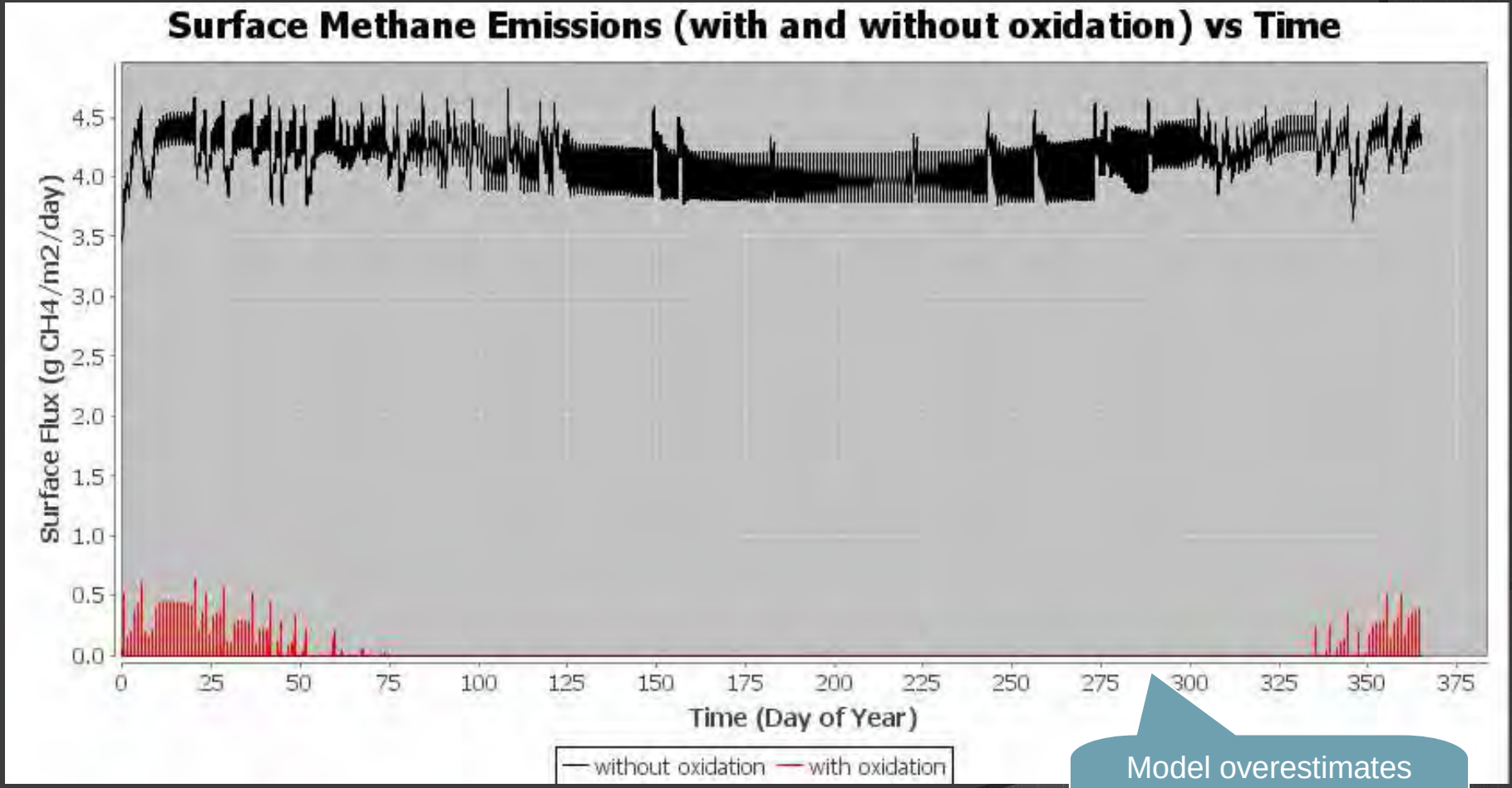
	Field Measurement ($g\ m^{-2}\ day^{-1}$)
March 2007	0.209
August 2007	0.564
March 2008	10.249
August 2008	8.860
Overall Range	0.2 to 10.2

Different locations

Comparing CALMIM Output



MDC



Model overestimates CH_4 oxidation for Daily Covers

Rates of CH_4 oxidation at various depths under 3 conditions:

- No Pre-incubation at field-collected moisture
- 60-day pre-incubation at field-collected moisture
- 60-day pre-incubation at field-capacity moisture (33 kPa)

	Marina			Scholl Canyon		
Depth (cm)	Daily	Intermediate	Final	Daily	Intermediate	Final
	(ug CH_4 g_{soil}^{-1} day^{-1})					
A. Initial Rate Š No Pre-incubation at field collected moisture contents						
0-10 cm	0.05 (0.02)	0.4 (0.2)	0.3 (0.1)	0.1 (0.2)	0.2 (0.3)	0.2 (0.1)
10-20 cm	0.04 (0.08)	1.9 (0.4)	0.2 (0.1)	0.1 (0.1)	0.2 (0.1)	0.2 (0.3)
20-30 cm	#	2.5 (0.6)	2.8 (0.5)	#	-	0.1 (0.1)
30-40 cm		171.3 (22)	2.6 (0.2)		-	-
40-50 cm		211.2 (36)	0.5 (0.3)		-	-
50-60 cm		#	1.4 (0.2)		-	-
70-80 cm			0.4 (0.2)		-	-
B. Pre-incubation with 50 ml l^{-1} CH_4 and 200 ml l^{-1} O_2 at field collected moisture contents						
0-10 cm	0.4 (0.2)	0.1 (0.3)	3.6 (0.5)	1.7 (0.2)	0.2 (0.1)	0.9 (0.2)
10-20 cm	1.8 (0.1)	1.9(0.1)	2.8 (0.4)	3.6 (1.4)	0.2 (0.1)	0.5 (0.1)
20-30 cm	#	8.9 (0.4)	5.6 (10)	#	-	0.2 (0.5)
30-40 cm		384.2 (10.3)	111.3 (12)		-	-
40-50 cm		374.1 (7.1)	199.8 (14)		-	-
50-60 cm		#	219.8 (28)		-	-
70-80 cm			212.7 (23)		-	-
C. Pre-incubation with 50 ml l^{-1} CH_4 and 200 ml $l^{-1}O_2$ (60 d) at field capacity moisture content (33 kPa)						
0-10 cm	142.2 (33)	416.8 (16)	593.8 (31)	112.4 (19)	211.4 (32)	212.9 (22)
10-20 cm	132.6 (20)	412.9 (13)	573.9 (14)	112.1 (13)	212.4 (39)	212.7 (18)
20-30 cm	#	412.7 (15)	613.1 (14)	#	-	212.5 (11)
30-40 cm		412.4 (23)	594.2 (16)		-	-
40-50 cm		452.0 (12)	604.2 (15)		-	-
50-60 cm		#	NS		-	-
70-80 cm			644.2 (28)		-	-

no pre-incub; field moist.
oxid. range = 0.05 -211

pre-incub; field moist.
oxid. range = 0.1 - 384

pre-incub; field capacity
oxid. range = 112 -644

(averages of 6 replicates; SD in parentheses)

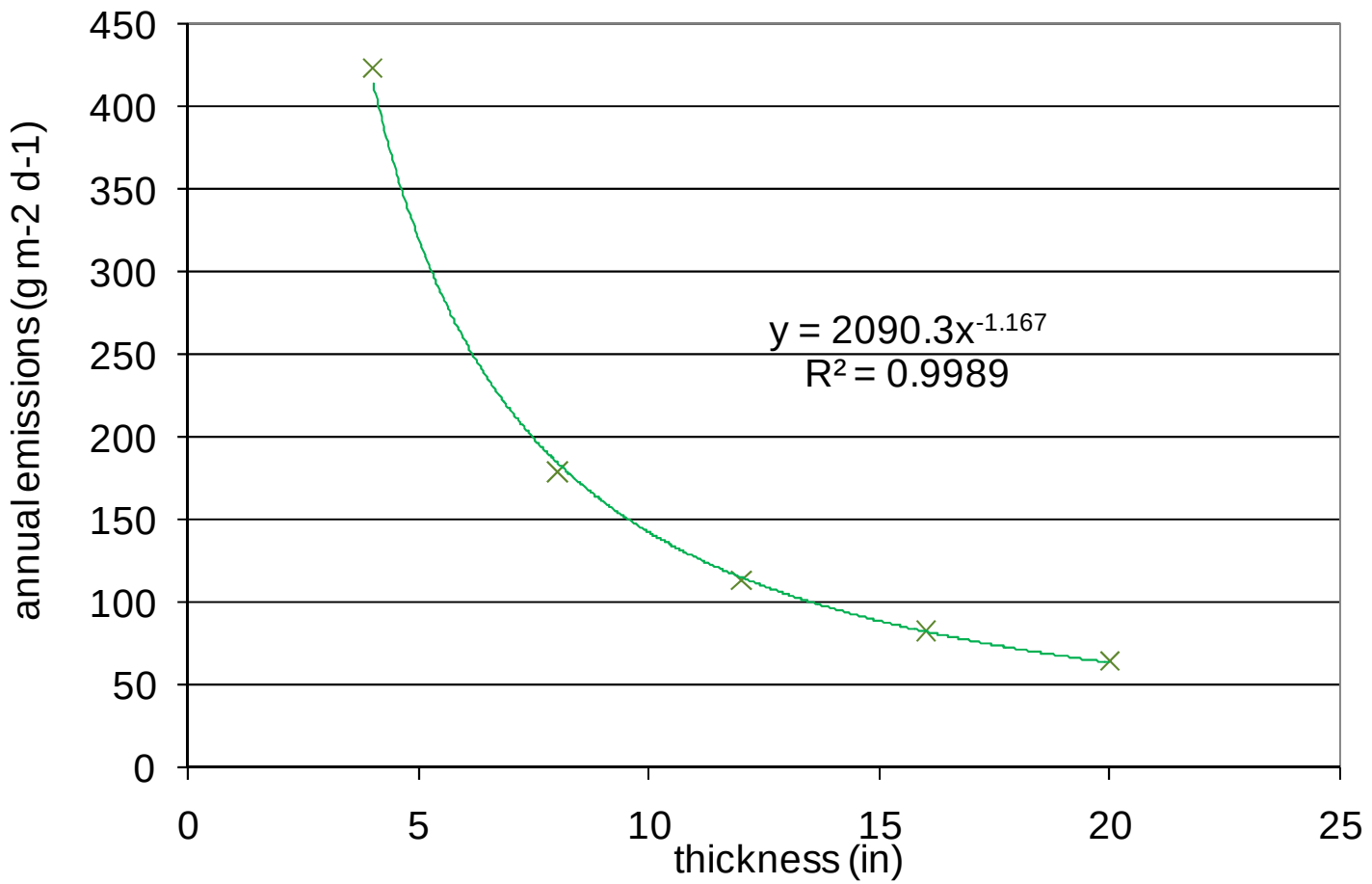
MDC: Cover Thickness

3000 ppm CH_4 at base of cover

Thickness	Surface Emissions with Oxidation ($g\ m^{-2}\ day^{-1}$)	Surface Emissions without Oxidation ($g\ m^{-2}\ day^{-1}$)
8”	3.49	7.64
12”	0.06	4.83
16”	0	3.52

Field data → 0.2 to 10.2 $g/m^2/day$

MDC: Cover Thickness



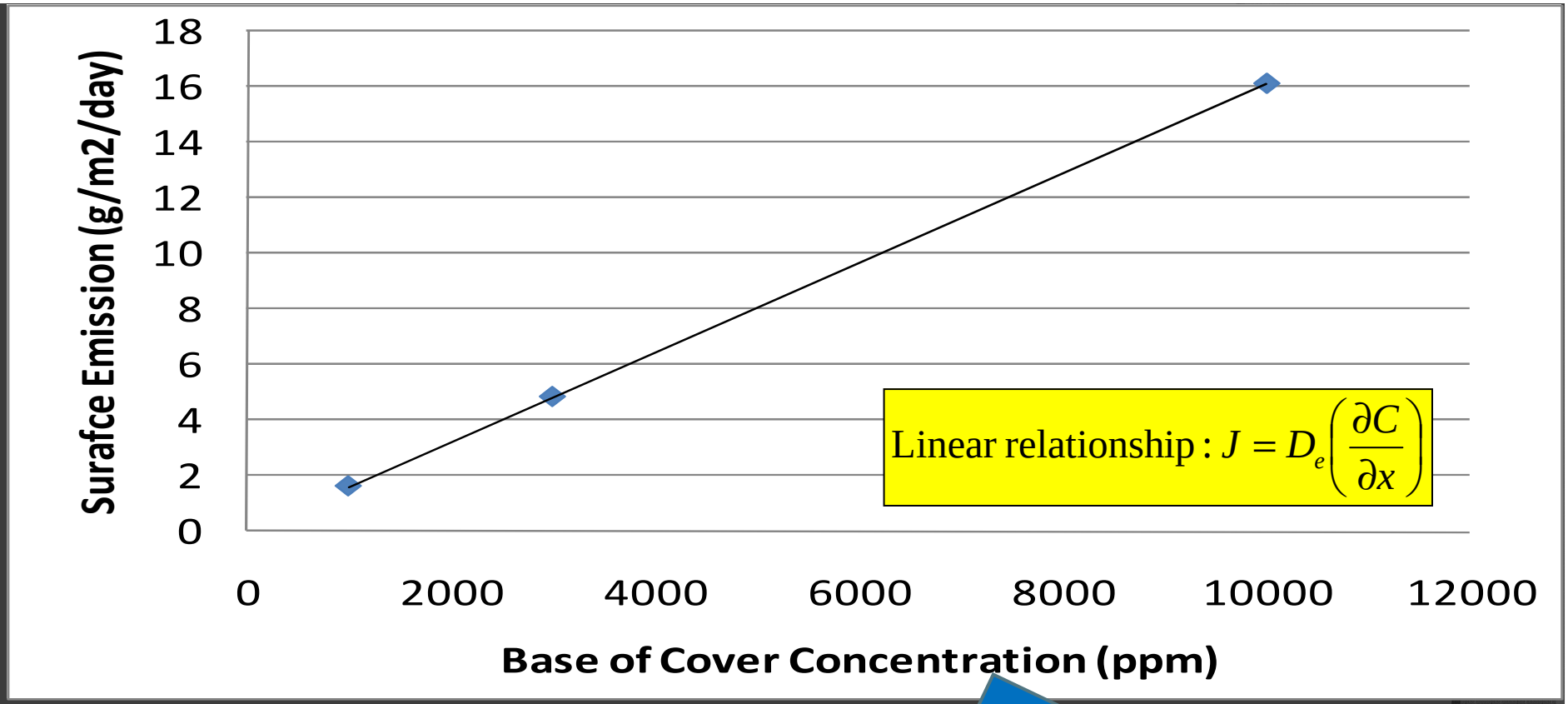
MDC: Concentration at Base of Cover

1000 ppm CH_4 at base of cover

3000 ppm CH_4 at base of cover

10000 ppm CH_4 at base of cover

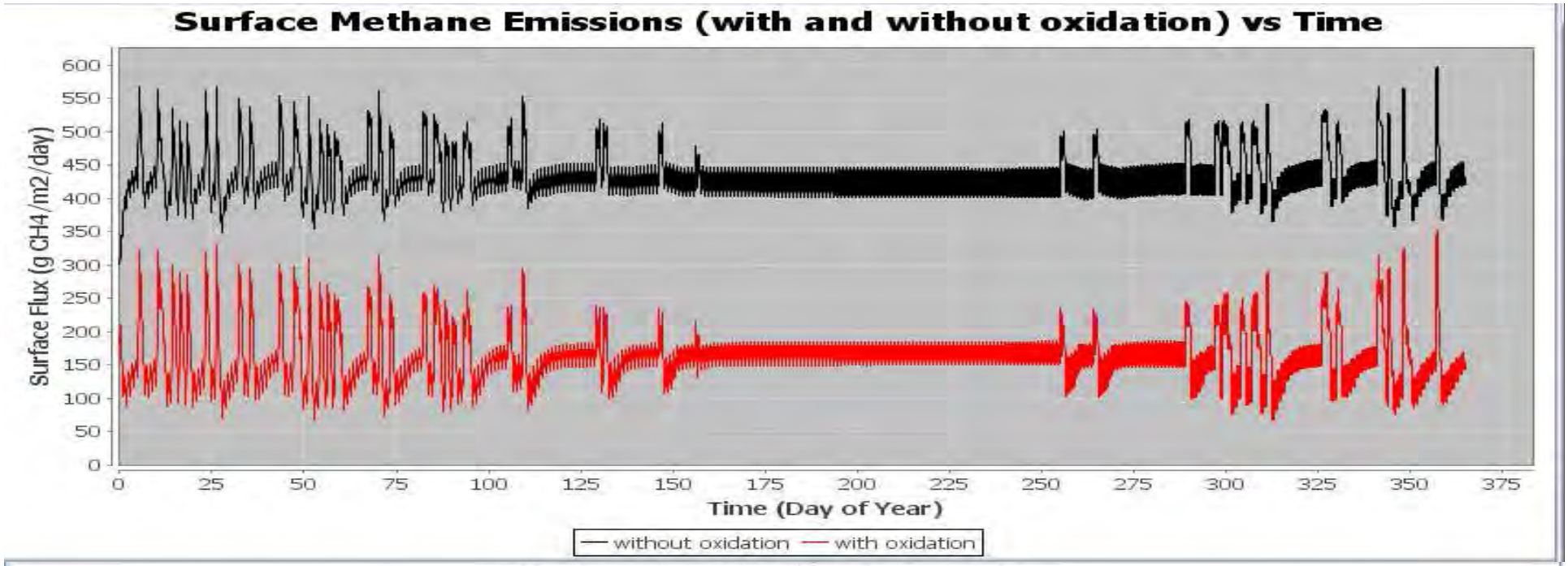
Concentration @ base of cover	Surface Emissions with Oxidation ($g\ m^{-2}\ day^{-1}$)	Surface Emissions without Oxidation ($g\ m^{-2}\ day^{-1}$)
1000 ppm	0	1.61
3000 ppm	0.06	4.83
10000 ppm	9.58	16.11

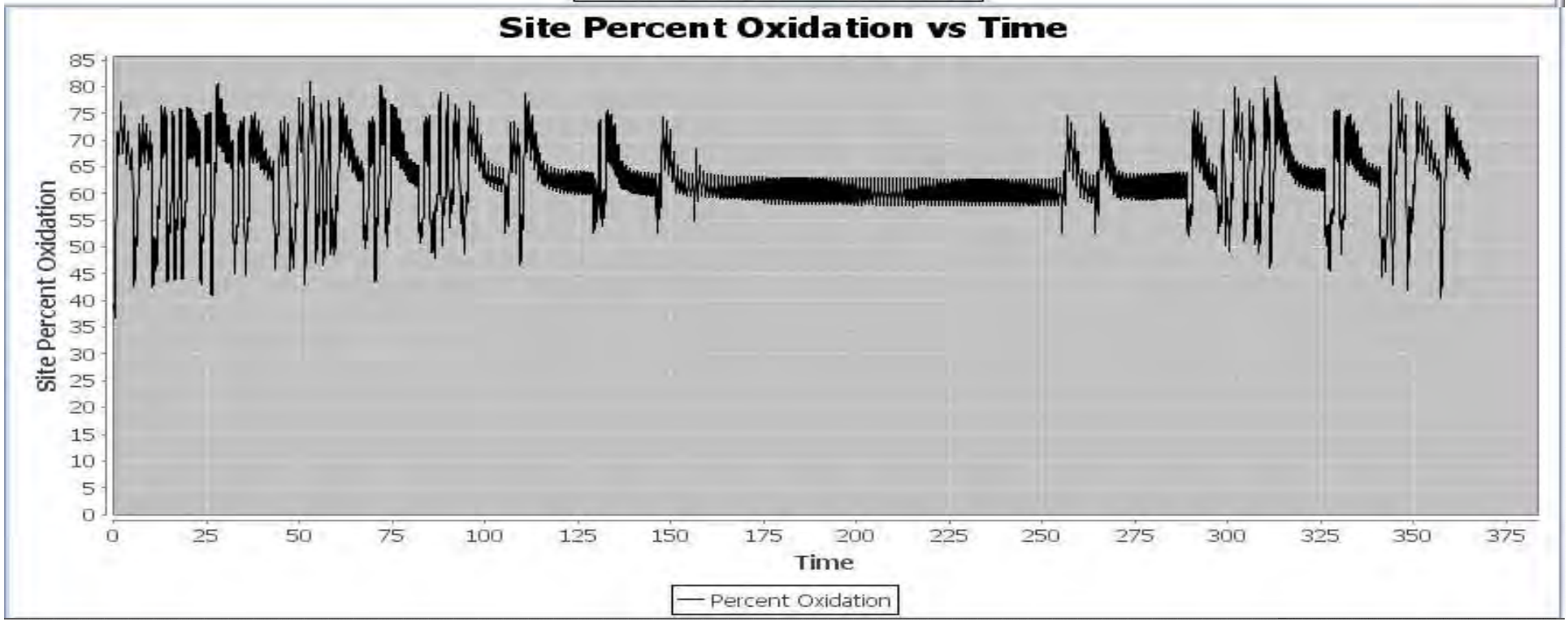


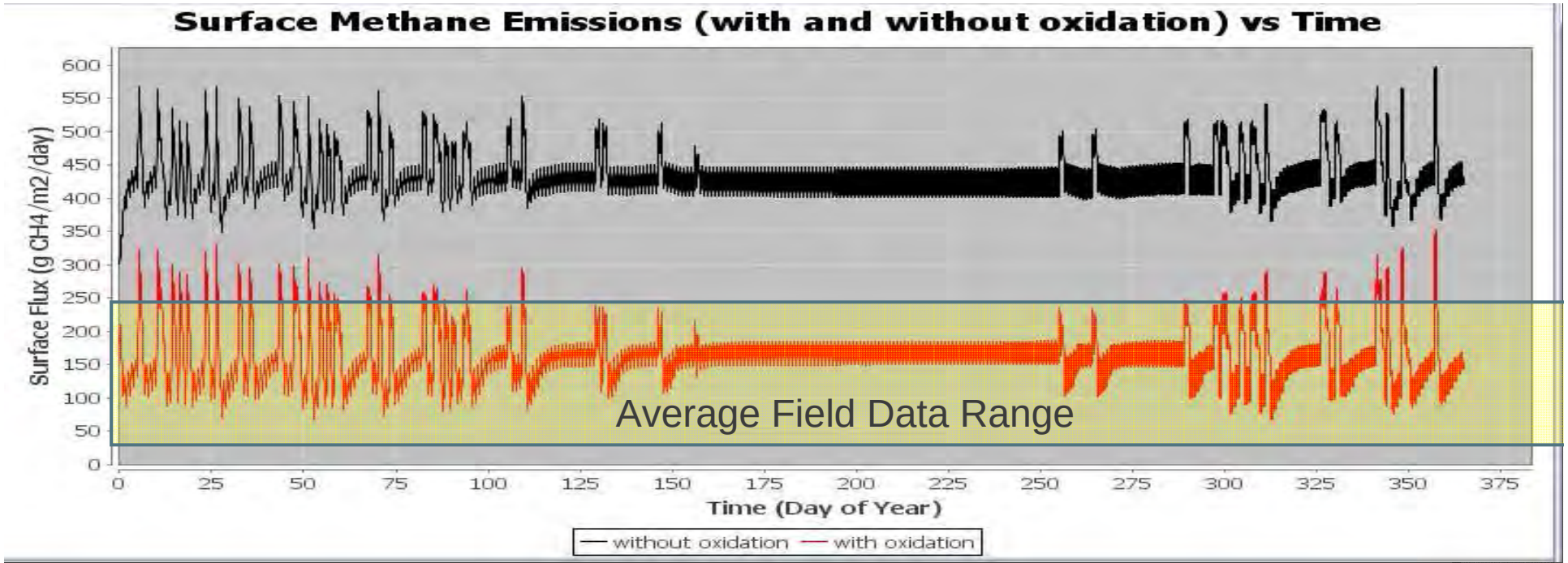
Concentration @ base of cover	Surface Emissions with Oxidation (g/m2/day)	ce Emissions ut Oxidation m2/day)
1000 ppm	0	1.61
3000 ppm	0.06	4.83
10000 ppm	9.58	16.11

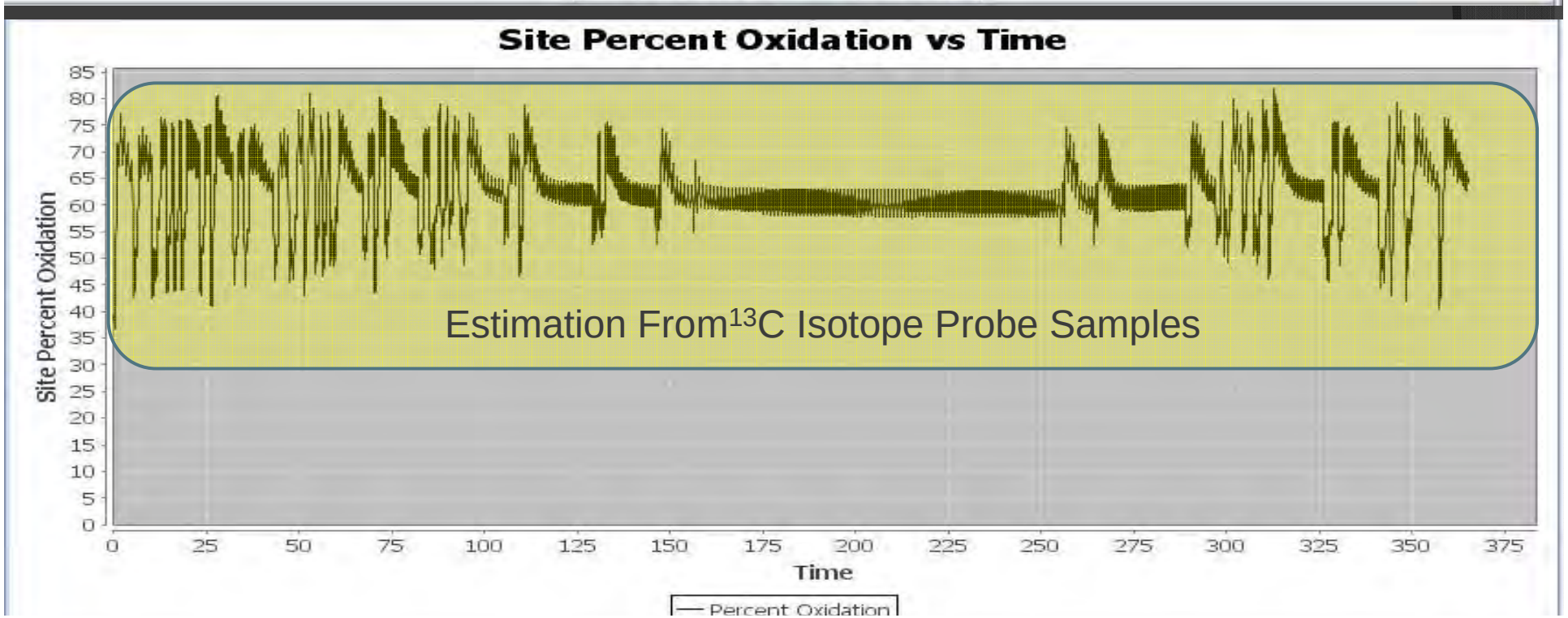
Marina Intermediate Cover

[Cover placed late 2006]	Field Measurement ($g\ m^{-2}\ day^{-1}$)	% CH_4 (v/v) at base of cover
March 2007	0.03	11.2
August 2007	53.17	40.7
March 2008	34.20	54.9
August 2008	237.81	54.4


Surface Methane Emissions (with and without oxidation) vs Time
Surface Flux (g CH4/m2/day)
Time (Day of Year)
without oxidation
with oxidation


Site Percent Oxidation vs Time
Site Percent Oxidation
Time
Percent Oxidation


Surface Methane Emissions (with and without oxidation) vs Time
Surface Flux (g CH4/m2/day)
Time (Day of Year)
without oxidation
with oxidation
Average Field Data Range


Site Percent Oxidation vs Time
Site Percent Oxidation
Time
Percent Oxidation
Estimation From13C Isotope Probe Samples

Marina Final Cover Comparisons

	Field Measurement ($g\ m^{-2}\ day^{-1}$)
March 2007	0.00
August 2007	0.00
March 2008	0.01
August 2008	0.10
Overall Average	0.03
CALMIM	0 with oxidation 23 without oxidation

Scholl Canyon : Daily Cover

	Field Measurement ($g\ m^{-2}\ day^{-1}$)
March 2007	0.003
August 2007	0.004
March 2008	0.008
August 2008	-0.001
CALMIM	<0.01

Scholl Canyon Intermediate Cover

	Field Measurement ($g\ m^{-2}\ day^{-1}$)
March 2007	-0.006
August 2007	0.002
March 2008	0.013
August 2008	-0.003
CALMIM	<0.01

Scholl Canyon Final Cover

	Field Measurement ($g\ m^{-2}\ day^{-1}$)
March 2007	0.006
August 2007	0.015
March 2008	0.019
August 2008	0.022
CALMIM	<0.01

Questions from Beta Testers

- Why are the emission results for different landfill sizes (waste in place) the same, if the same cover and cover type (e.g. concentration profiles) are used?
  - The assumptions for this model:
    - Diffusion is the dominant transport mechanism: Concentration gradient controls gas transport

If concentrations are equal, then emissions are equal

Advection requires connectivity (e.g. soil cracks) for gas flow.

$$J = D_e\left(\frac{\partial C}{\partial x}\right)$$

Questions from Beta Testers

- Why are the emission results for different landfill sizes the same (i.e. waste in place), if the same cover and concentration profiles are used?
  - The assumptions for this model:
    - Diffusion is the dominant transport mechanism
    - Concentration gradient controls gas transport
  - Departure from first-order gas generation modeling
  - Potentially an easier to measure field parameter (gas concentration at base of cover) versus degradation constants/WIP stats/composition data…
    - Greatly reduces uncertainty in the modeling for inventory purposes

Other comments from Beta Testers

- Additional user guidance needed
  - Completing user manual
- Output written to Excel compatible files
  - Worksheet tabs with output as a function of date and depth of various properties
  - Created in “My Documents\CALMIM-DataOutput\SiteName\”
- Final Modifications being Completed
  - Still reducing memory leaks.. working with the programmers of the various libraries to improve memory performance

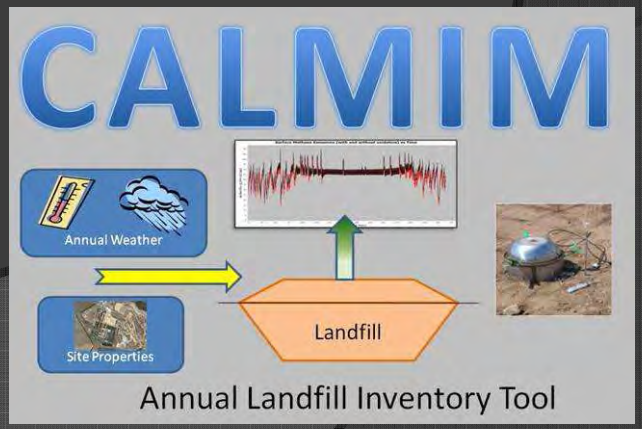
Summary and Conclusions:

Project has developed a new GHG Inventory Methodology for landfill methane based on:

- expansion and integration of existing field-validated modeling approaches for meteorology and soil microclimate, including use of publicly-available climatic databases
- site-specific cover soils and areas with gas recovery
- new modeling for methane emissions inclusive of seasonal methane oxidation in cover soils
- field validation over 2 annual cycles
- supporting laboratory incubation studies for methane oxidation
- Just the first step ; not the end of the road

Model available at:

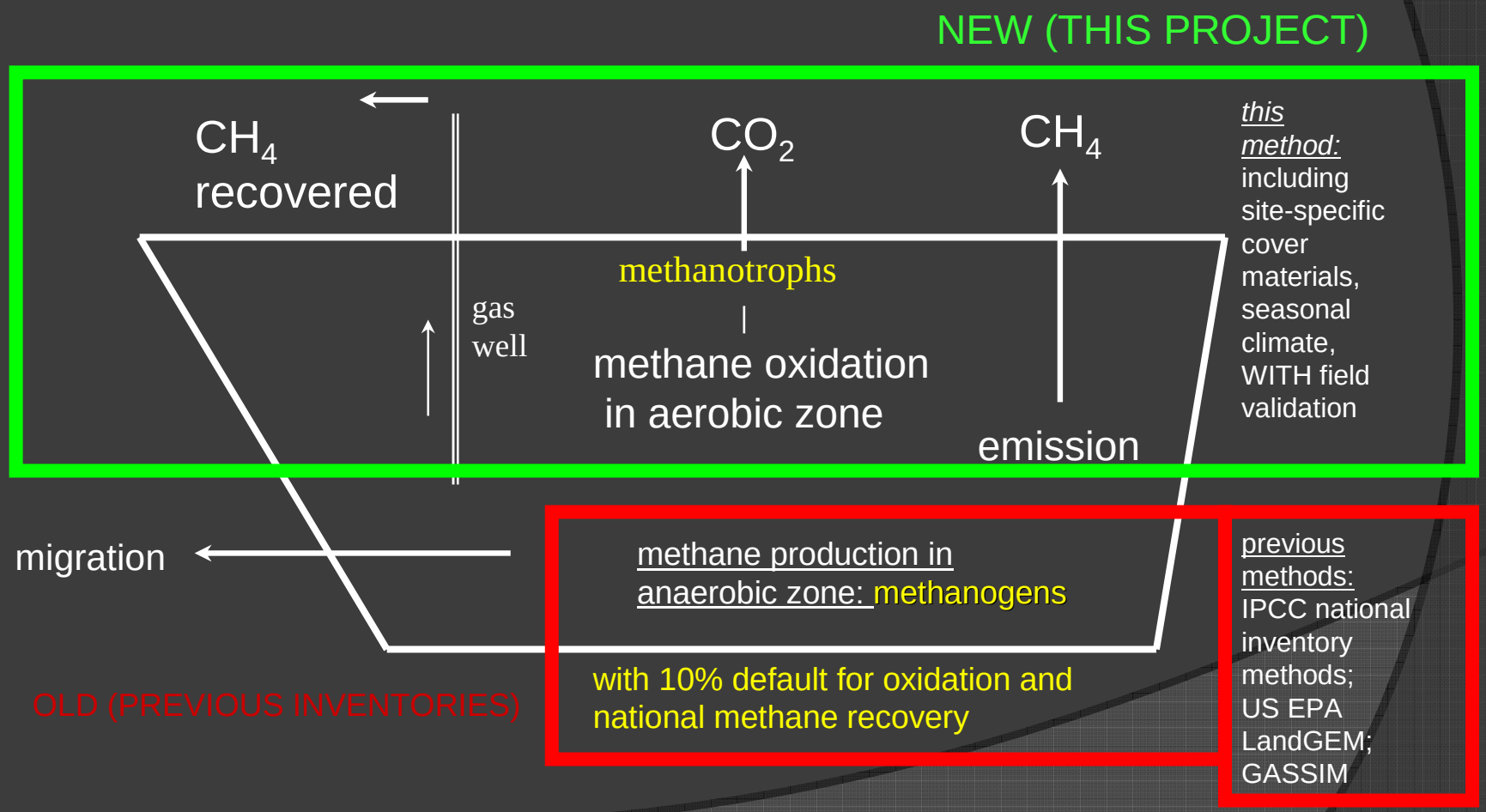
http://calmim.lmem.us



The difficulty lies, not in the new ideas, but in escaping the old ones, which ramify, for those brought up as most of us have been, into every corner of our minds

-John Maynard Keynes

Quoted in: K. Eric Drexler Engines of Creation: The Coming Era of Nanotechnology, Bantam, New York, 1987, p 231.



Acknowledgments: CEC, CIWMB, ARB

Special thanks to the field sampling crew:
Chad Rollofson, Martin duSaire, and Dean Peterson

Field Validation Sites:

Scholl Canyon Landfill (Los Angeles County Sanitation Districts)

Marina Landfill (Monterey Bay Regional Waste Management Authority)