Agricultural Strategies for Mitigating GHG Emission: DNDC Model and Case Studies

February 18, 2010

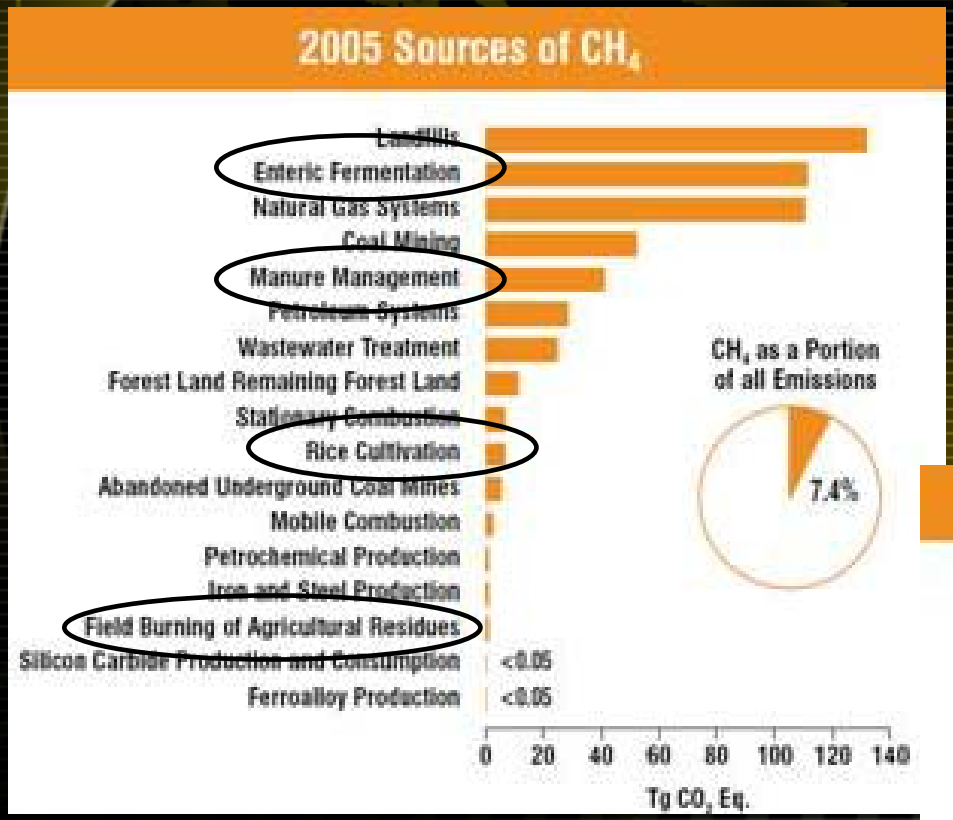
Dr. William Salas
Applied Geosolutions, LLC
87 Packers Falls Road
Durham, NH 03924 USA
wsalas@agsemail.com

APPLIED GEOSOLUTIONS, LLC

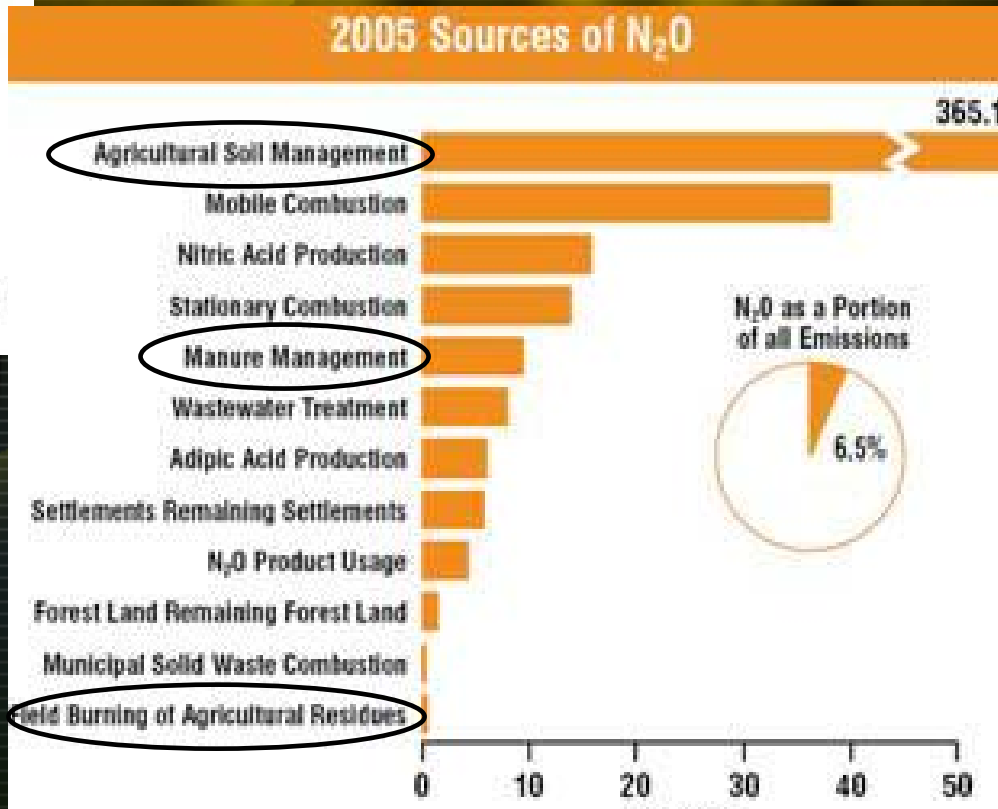
Overview

- Sources and estimation methodologies of agricultural of greenhouse gases (GHG)
- Overview the DNDC models,
- How well does the model work? Discussion of model validation,
- California rice case study: Using the model for GHG inventory and assessing mitigating opportunities.

Agricultural CH4 and N2O Emissions



Ag ~35% of total CH4 emission



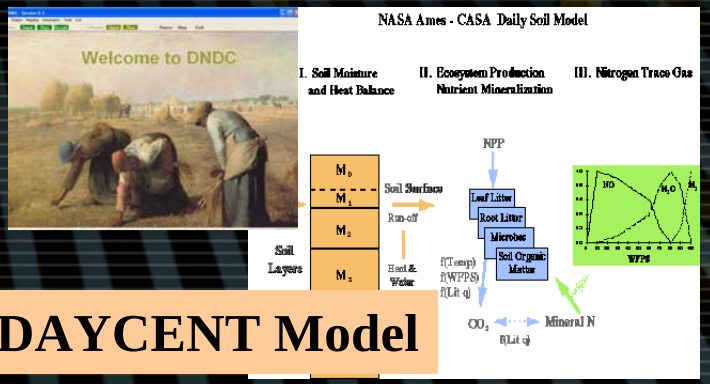
Ag ~73% of total N2O emission

Source: USEPA GHG Inventory

How do we estimate GHG emissions from agriculture?

- Measurements
  - ✓ Micrometerological methods: area sources
  - ✓ Flux chambers: site specific
- **Emission Factors**
  - ✓ Use activity data * EF (e.g. N2O emissions = 1% of Nitrogen applied to crops)
- Models
  - ✓ Simple empirical models
  - ✓ Mechanistic (also known as process models)

E = A x EF x (1-ER/100)
where:
E = emissions;
A = activity rate;
EF = emission factor, and
ER =overall emission reduction efficiency, %



DAYCENT Model

What are Process-based Models?

- Process-based modeling refers to biochemical and geochemical reactions or processes
- **Biogeochemical processes**… like decomposition, hydrolysis, nitrification, denitrification, etc…
- True process-based models **do not rely on constant emission factors**.
- They simulate and track the impact on emissions of varying conditions within soil and crop environment

Why do we need Process Models?

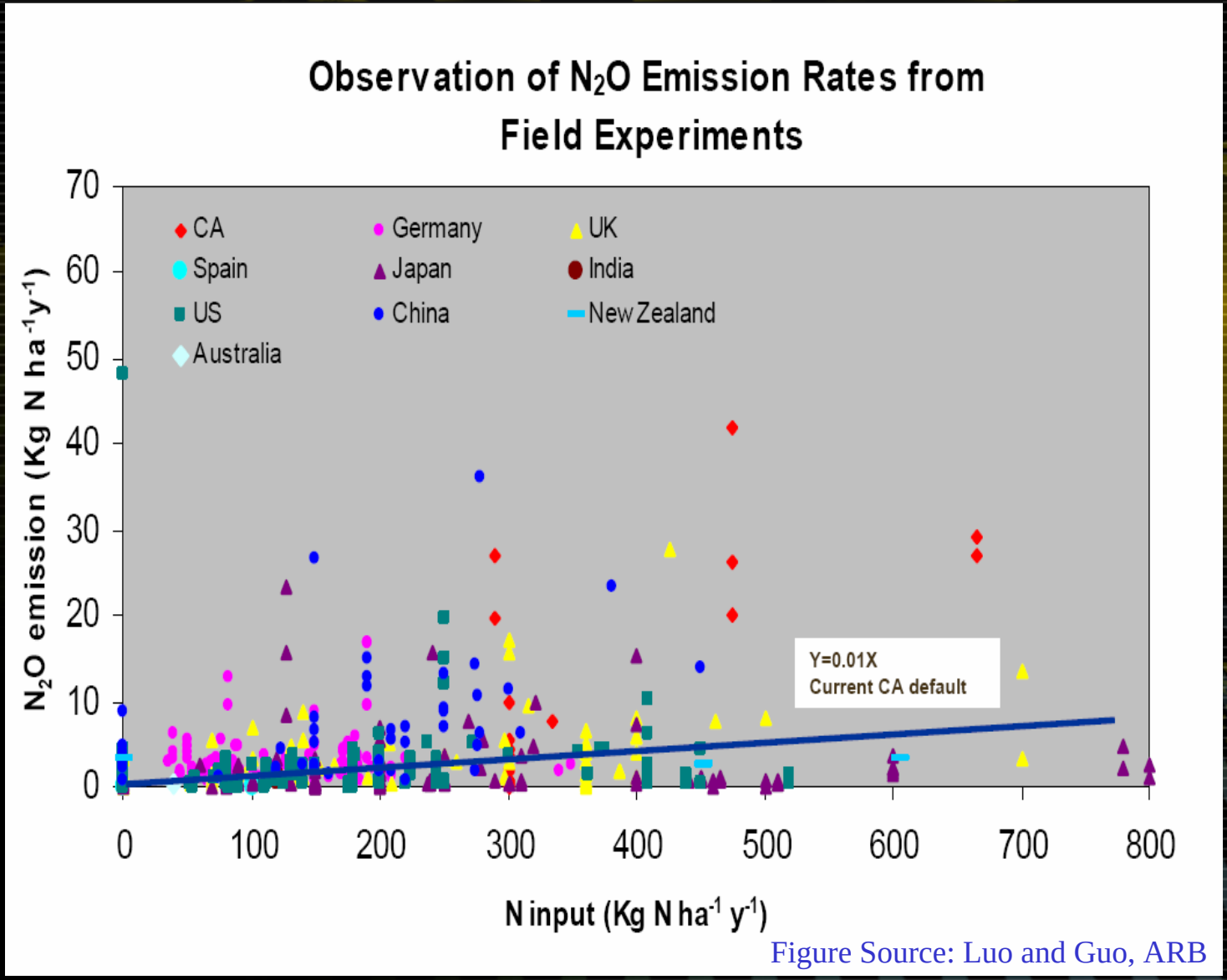
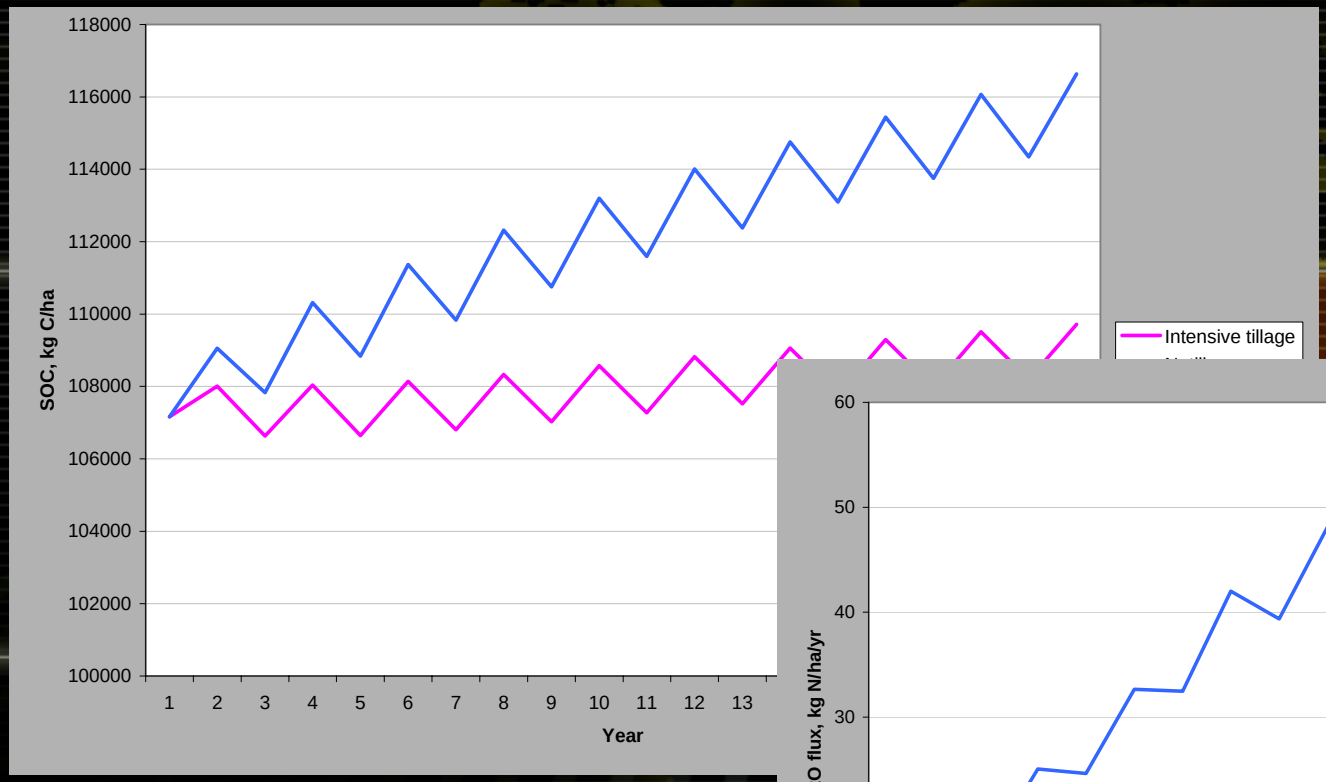
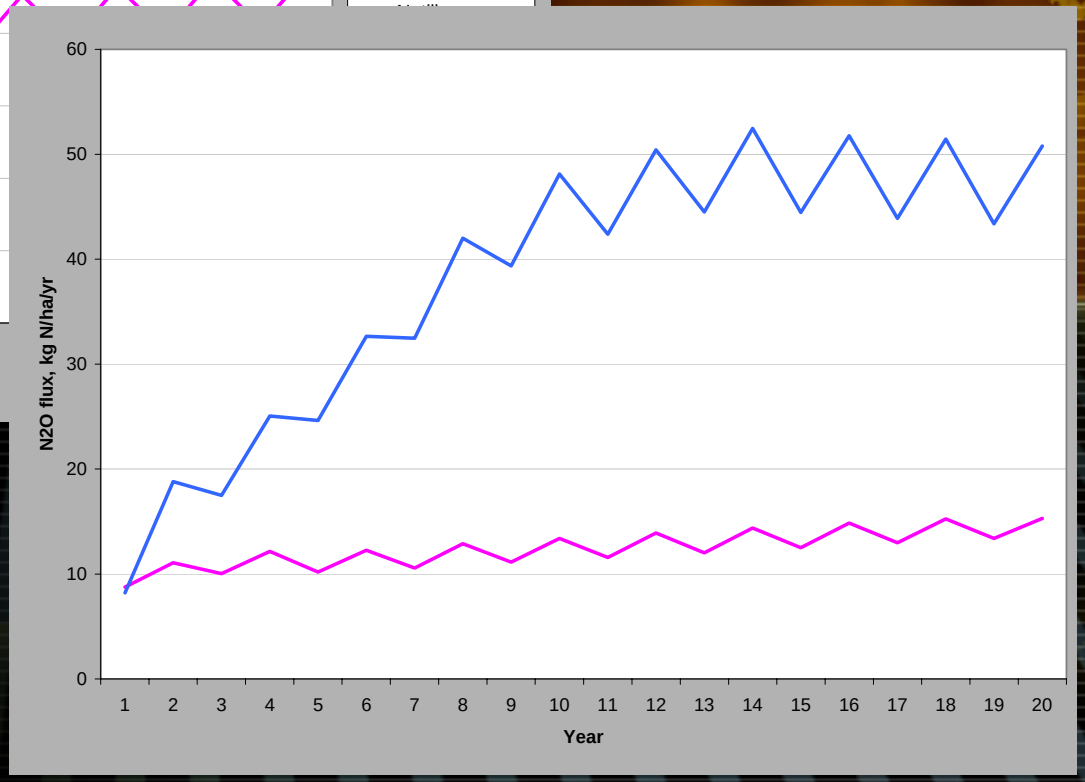


Figure Source: Luo and Guo, ARB

Role of Soil Carbon in CH_4 and N_2O Mitigation in Agricultural Soils





Unexpected Consequences?

	C sequestration	N_2O flux	SOC-GWP	N_2O-GWP	Net GWP
	kg C/ha/yr	kg N/ha/yr	kg CO_2 equivalent/ha/yr		
Intensive tillage	125	11.5	-459	5615	5156
Notill	468	21.1	-1716	10301	8585

- Static emission factors do not capture spatial or temporal variability in emissions across range of management alternatives…
- Need tools for comprehensive assessment (C sequestration, CH4 and N2O) of potential mitigation projects.

Advantage of Process-based Models

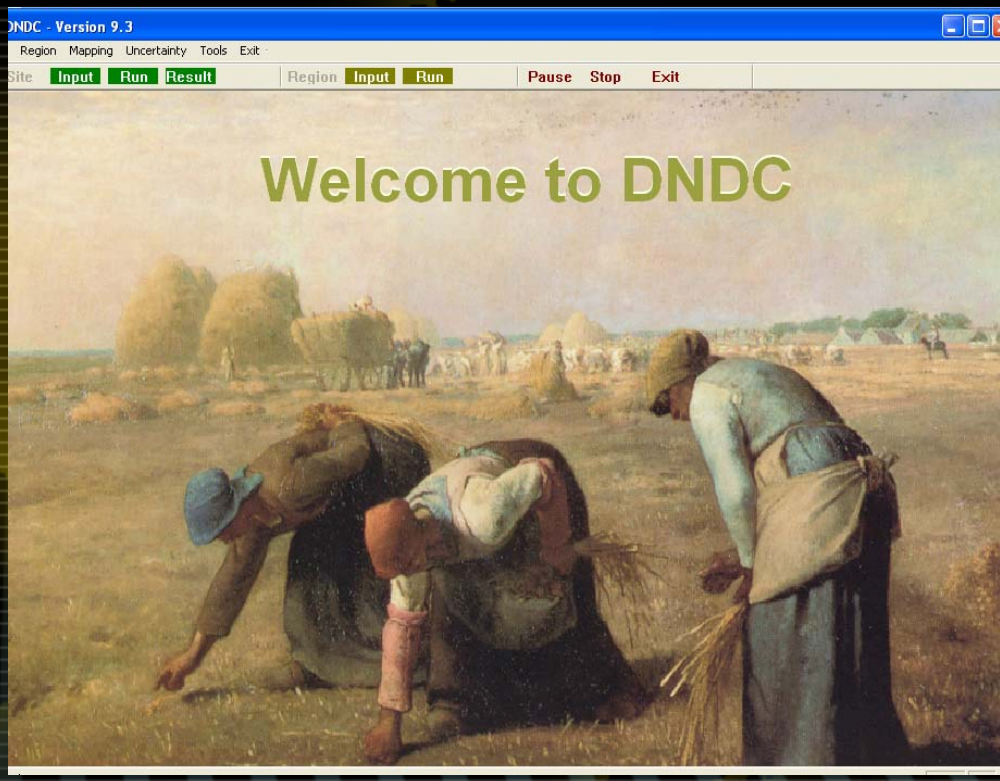
- Capture impact of soils on C and N cycling and GHG emissions
- Capture variability of weather/climate on C and N cycling
- Can be used to simultaneously assess impact of management practices on crop yields and GHG emissions
- Can be used to assess a wide range of ecosystems services (climate, food/fiber, air quality, water quality)

DNDC Model

DNDC stands for **D**e**n**itrification and **D**e**c**omposition, two processes dominating losses of N and C from soil into the atmosphere, respectively.

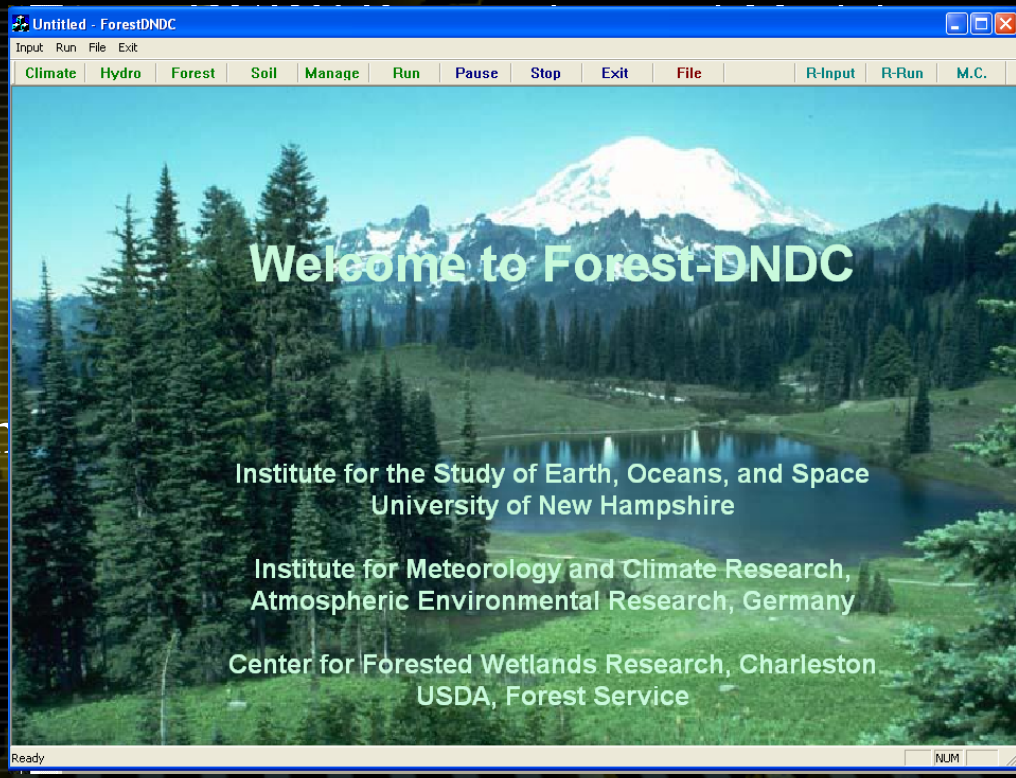
DNDC Biogeochemical Model Suite:

- DNDC
  - ✓ First model, development started in 1990
  - ✓ Initial focus on N2O
  - ✓ Focus on crop lands (>20 types of crops)
  - ✓ Models CO2, CH4, N2O, and crop growth/yields



DNDC Biogeochemical Model Suite:

- Forest and Wetland DNDC
  - ✓ Added forest growth/physiology model to DNDC
  - ✓ Simulates both wetlan and upland forests
  - ✓ Can simulate seasonally flooded systems

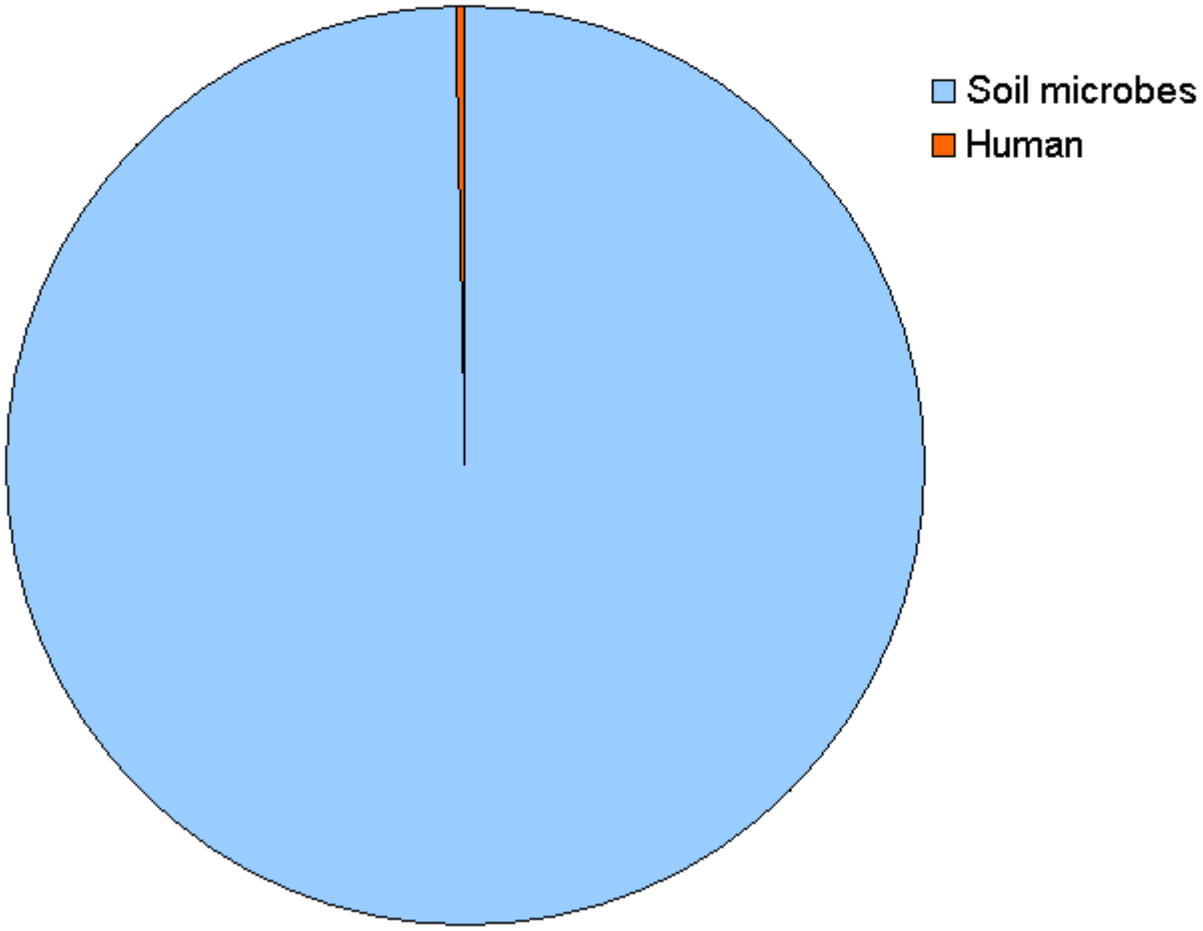


DNDC Biogeochemical Model Suite:

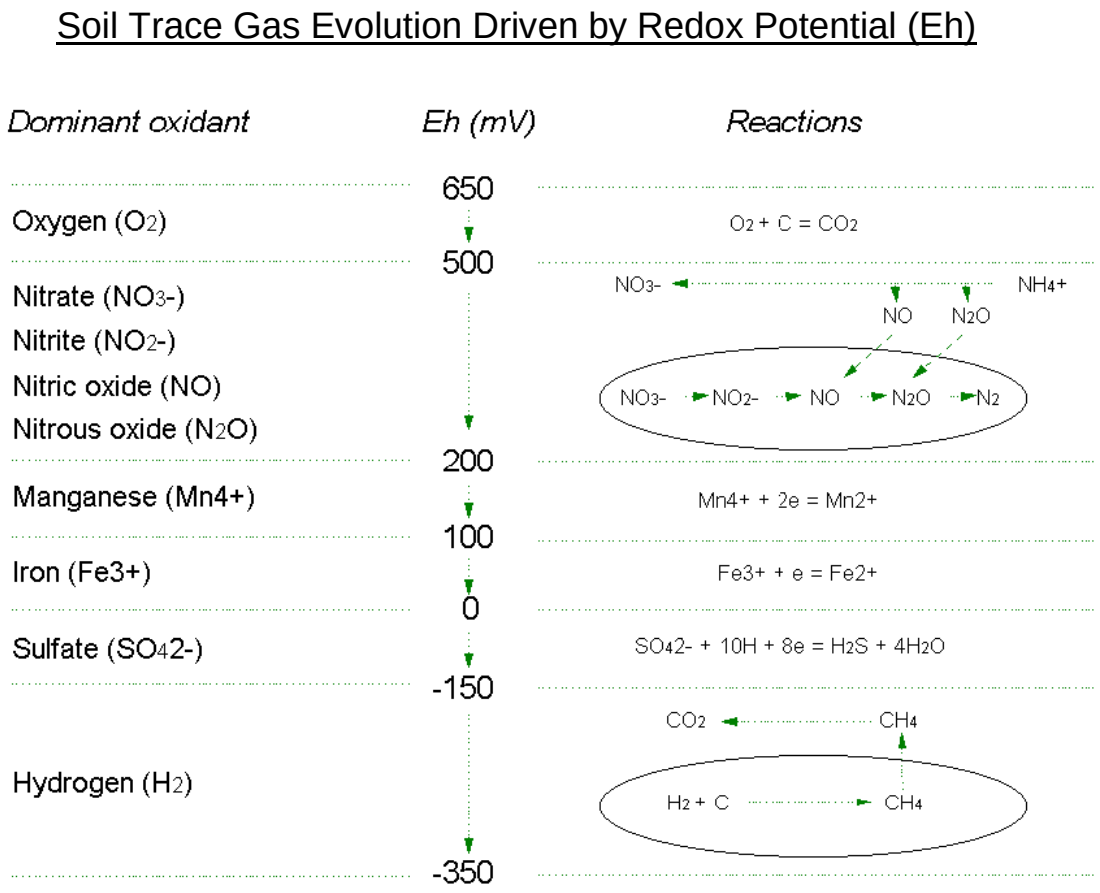
- Manure-DNDC
  - ✓ Simulates full C and N cycling for animal feeding operations.
  - ✓ Models GHG and NH3 emissions from Animal, manure storage and management, and land application of manure.

Quantifying GHG Emissions from Soils: Scientific Basis and Modeling Approach

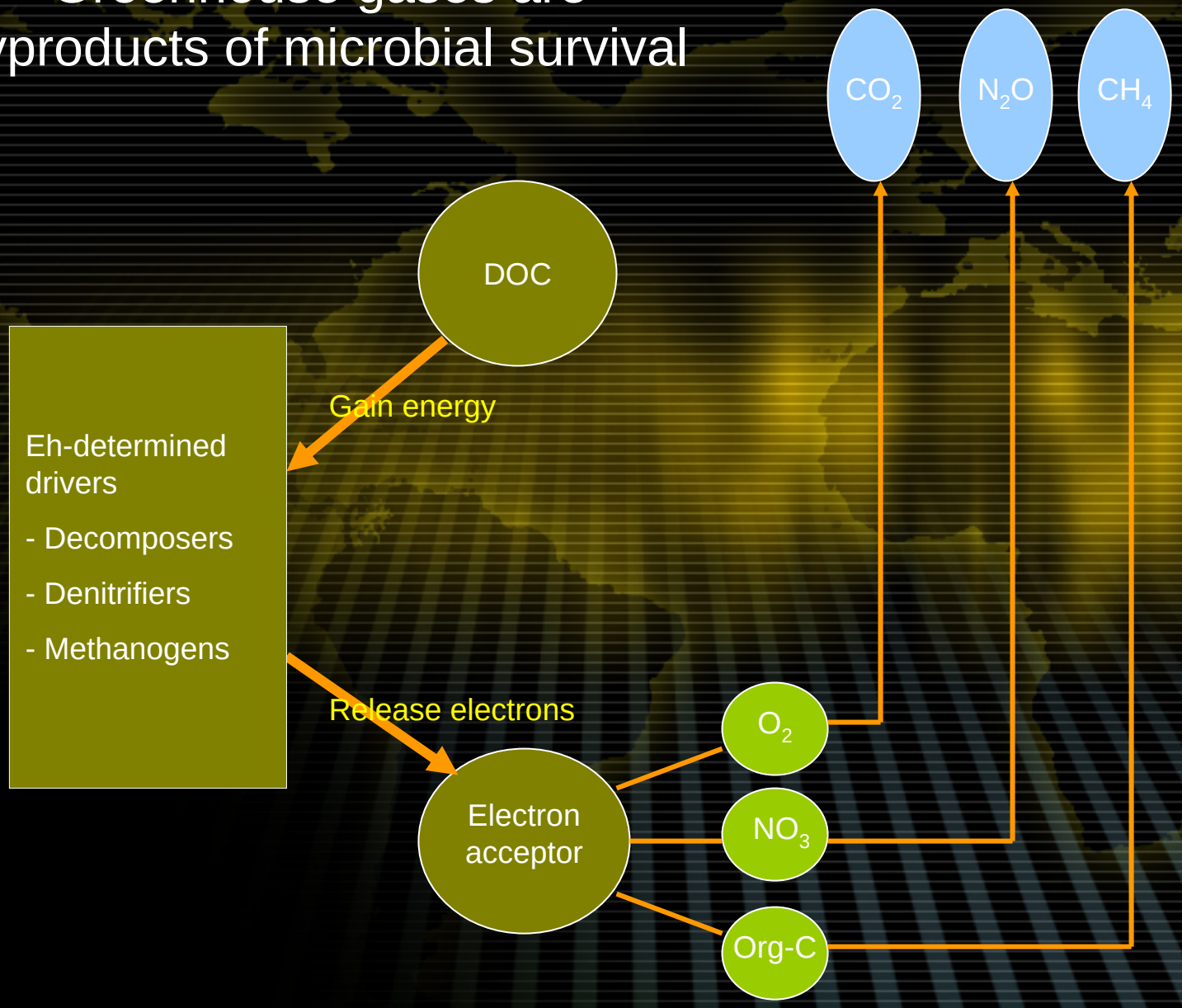
The Earth‘s Biomass: Soil Microbes (31100 Tg C) vs. Human (98 Tg C)



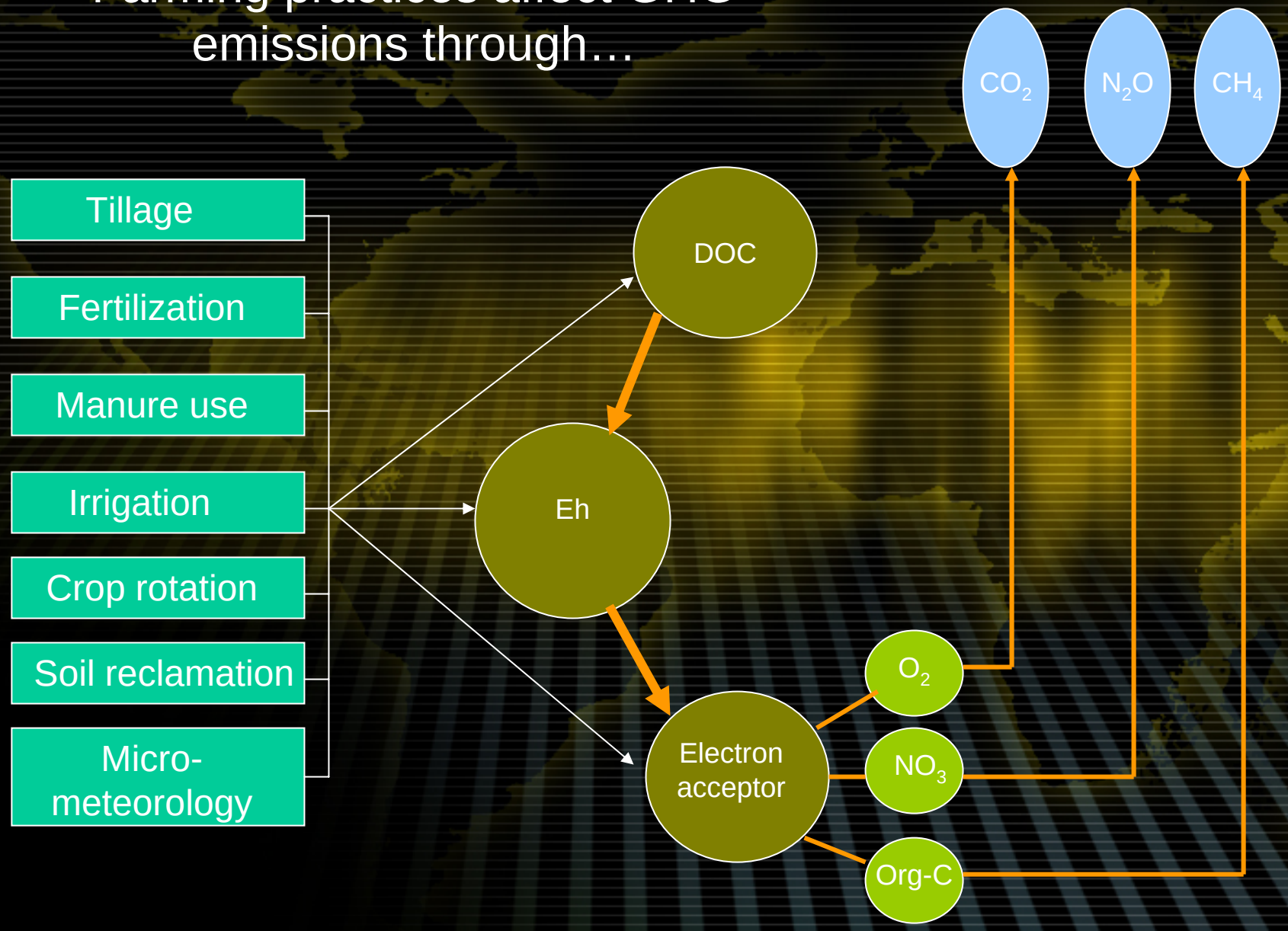
Scientific Basis



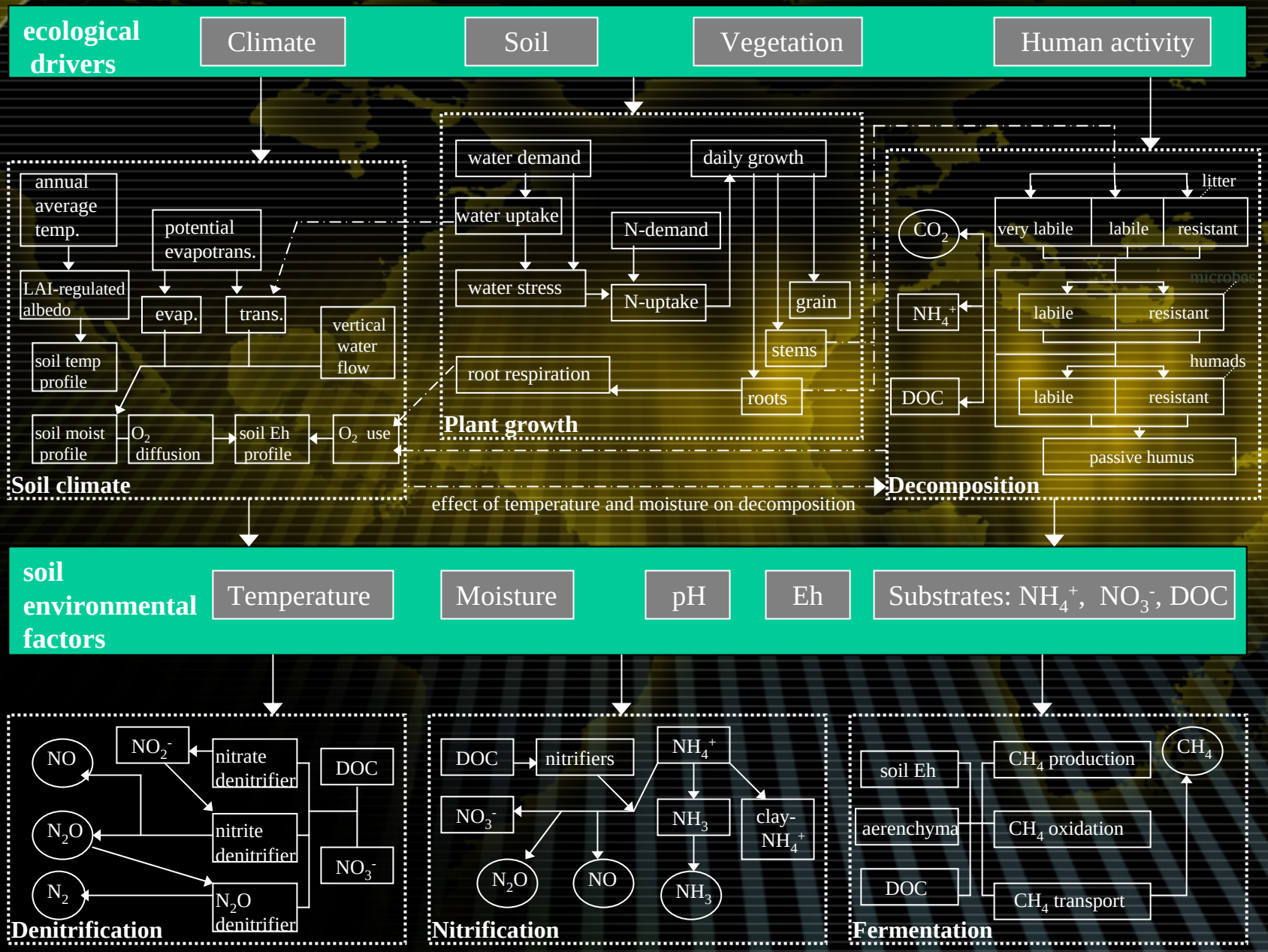
Greenhouse gases are byproducts of microbial survival



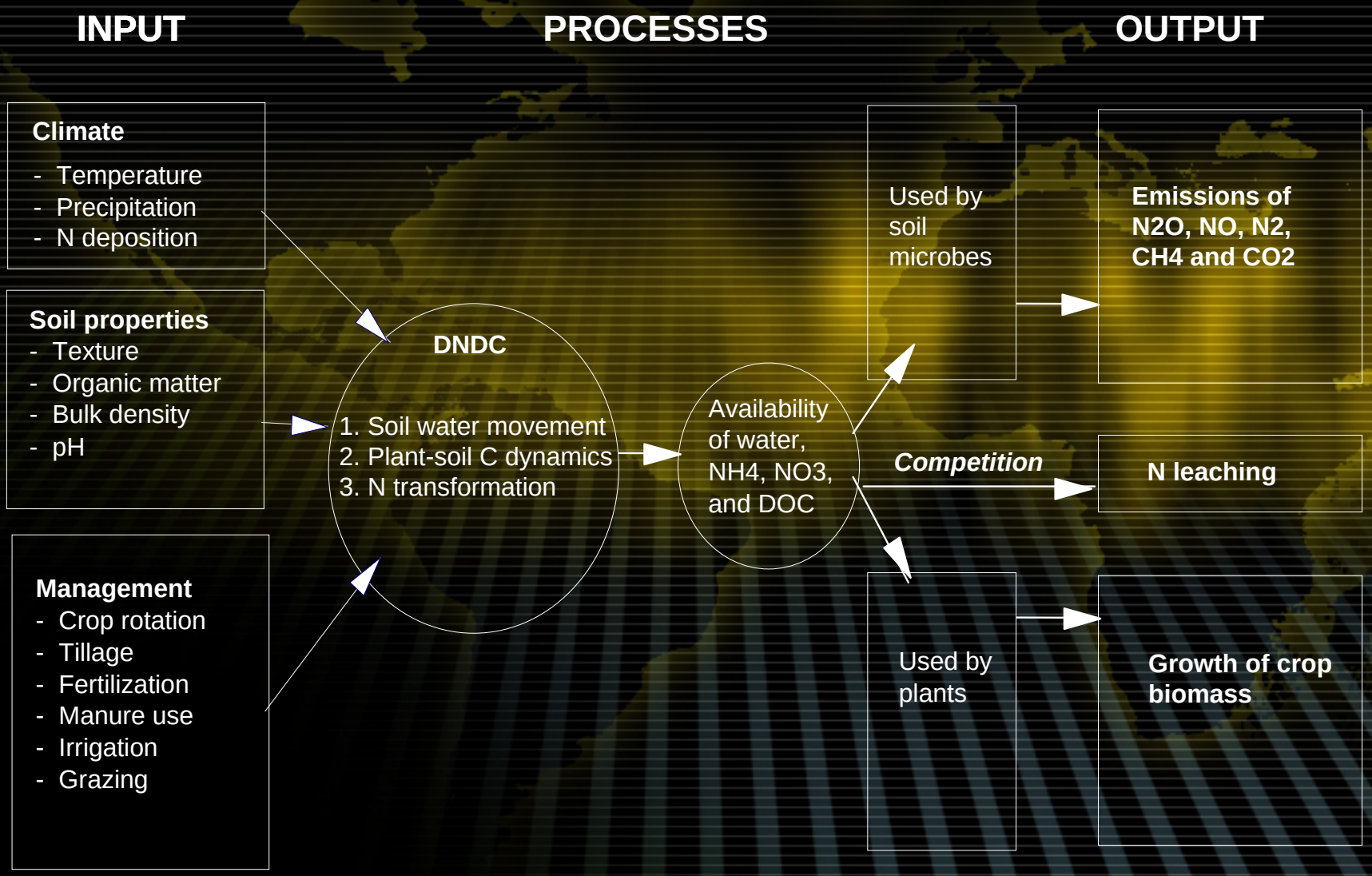
Farming practices affect GHG emissions through…



The DNDC Model



DNDC bridges between ecological drivers and GHG emissions



Model Validation…

- Rigorous model validation is key for acceptance (scientific and market)
- Lack of appropriate field data for process-model validation
- DNDC has been validated extensively for agroecosystems worldwide (over 100 peer review papers)
- Additional validation efforts underway for California cropping systems

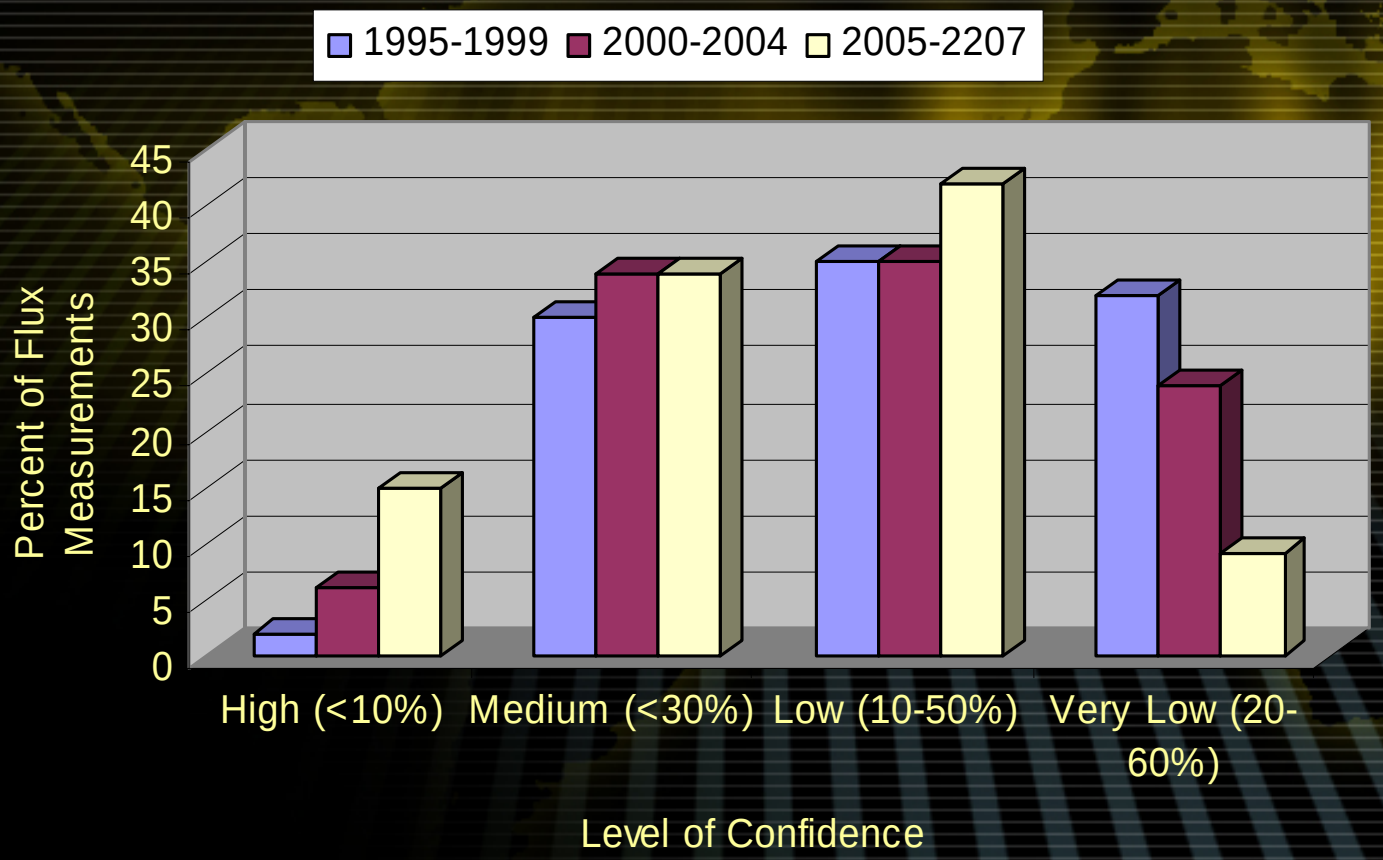
Field Measurements of N2O and CH4

- Measurement approaches:
  - ✓ Flux chambers: site specific – useful for model validation if all model inputs are known
  - ✓ Micrometerological methods: area sources – useful for evaluating regional model simulations (scaling from site to region)

- Accuracy/uncertainty of measurements?

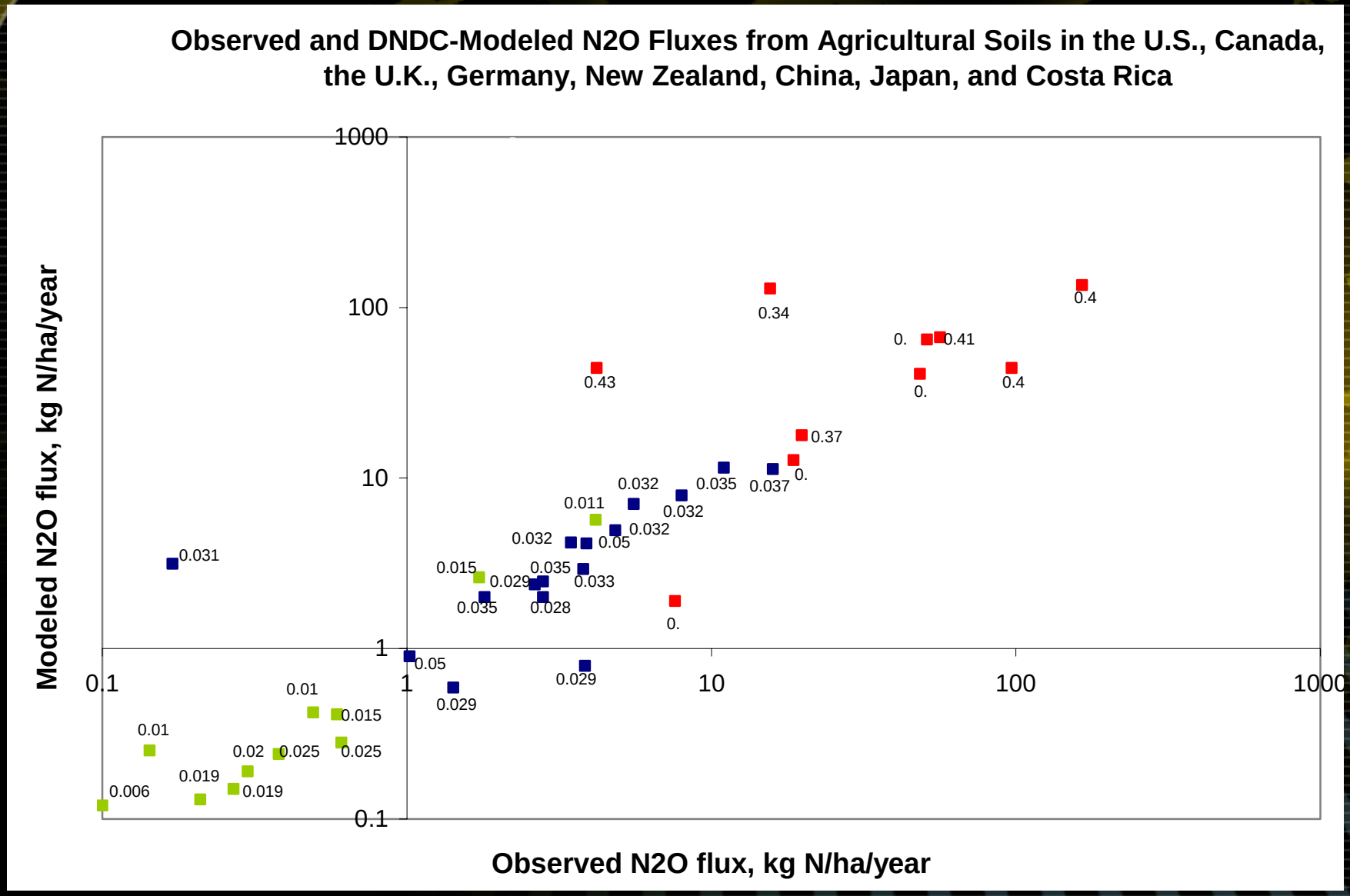
Field Measurements & Uncertainty

- Uncertainty of field measurements due to methods is quite variable.



Source: Rochette and Eriksen-Hamel, SSSAJ:72(2) March-April 2008

Nitrous Oxide Validation



Model Evaluation

Coefficient of determination, R^2
Provides a measure of how well future outcomes are likely to be predicted by the model (0-1)

$$R^2 \equiv 1 - \frac{SS_{\text{err}}}{SS_{\text{tot}}},$$

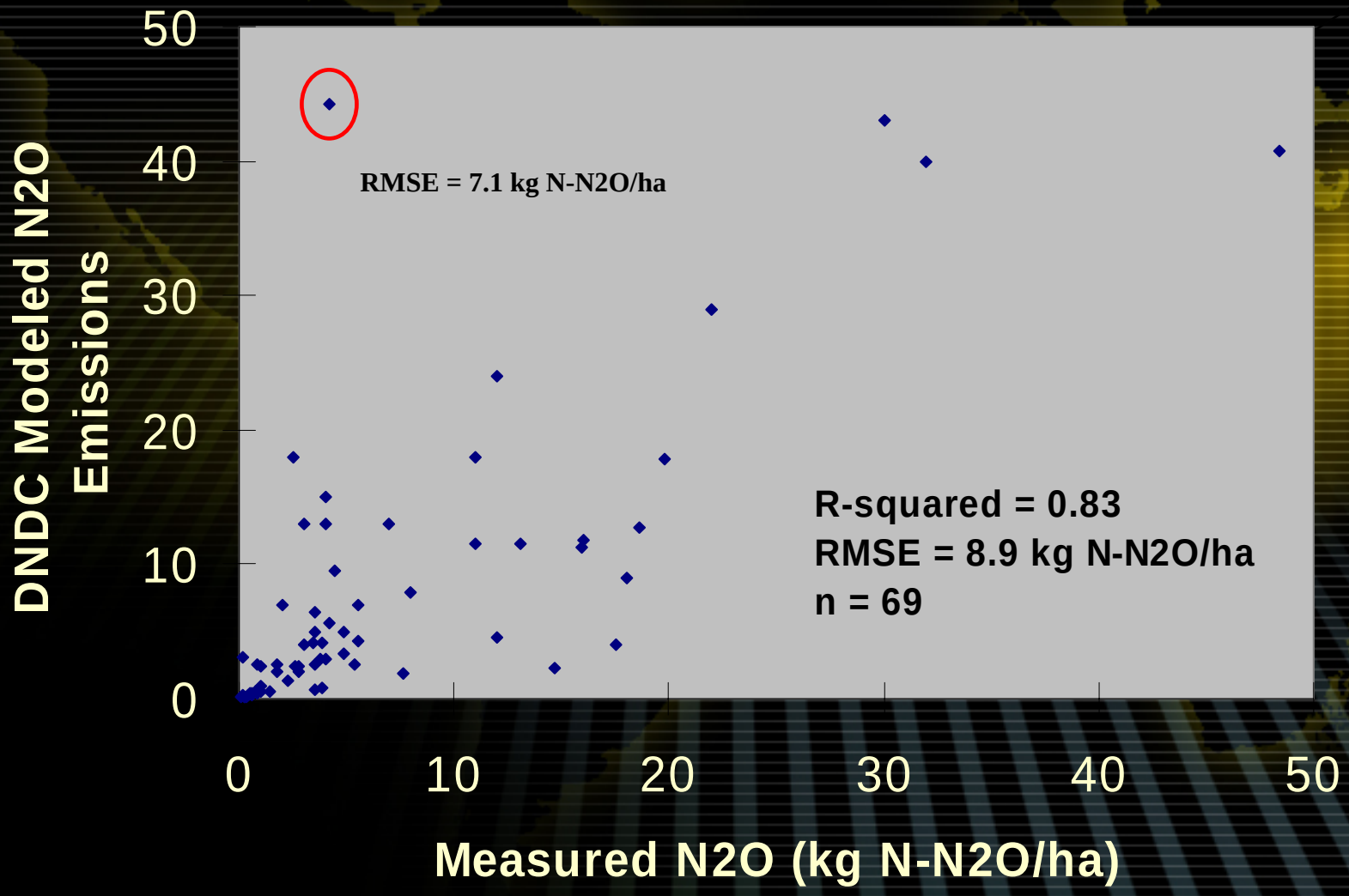
$$SS_{\text{tot}} = \sum_i (y_i - \bar{y})^2,$$

$$SS_{\text{err}} = \sum_i (y_i - f_i)^2$$

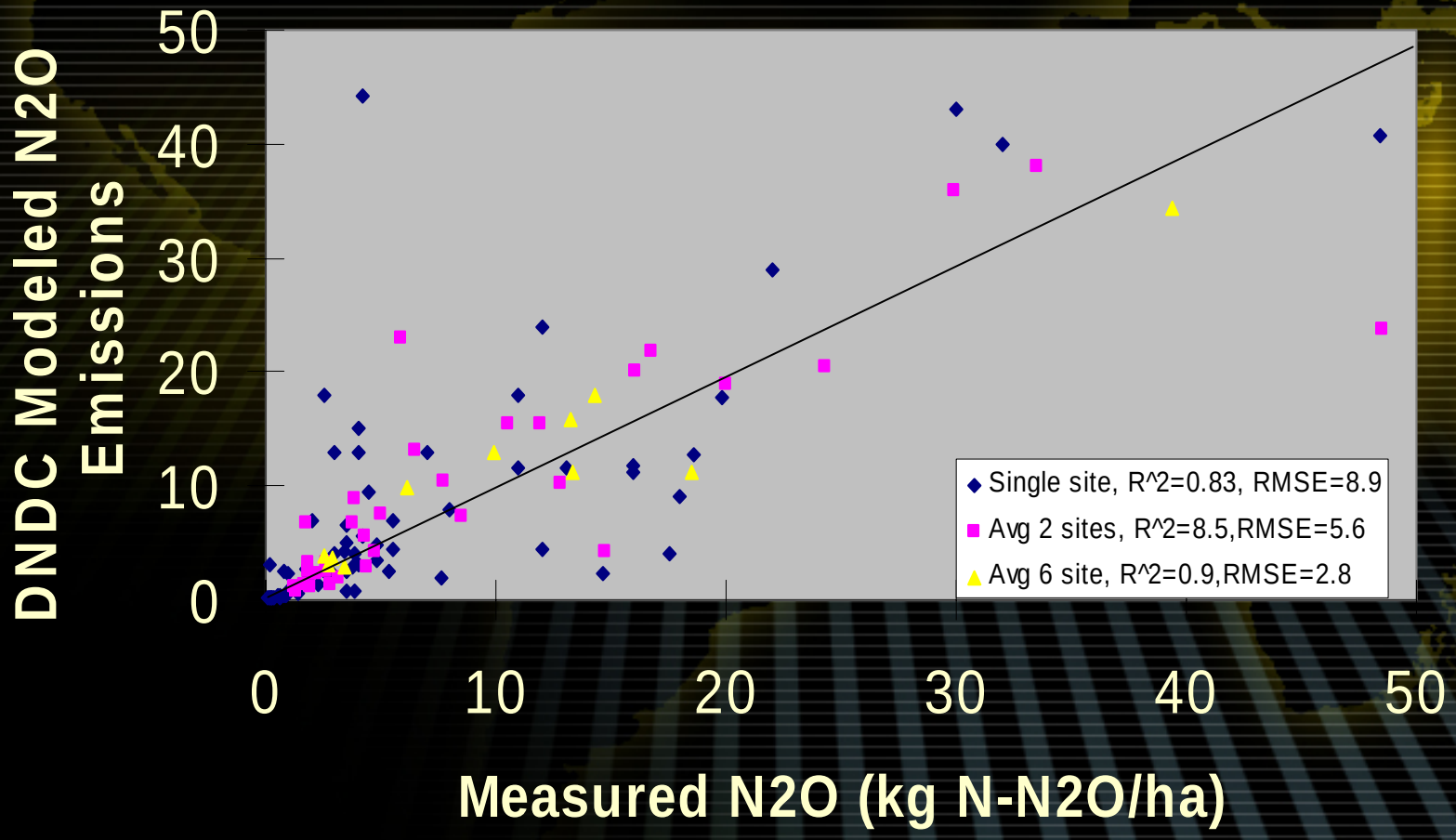
Root mean square error (RMSE)
A measure of the precision of the model in comparison with the field measurements. Units are the same as the model units.

$$\sqrt{\frac{\sum_{i=1}^{n} (x_{1,i} - x_{2,i})^2}{n}}$$

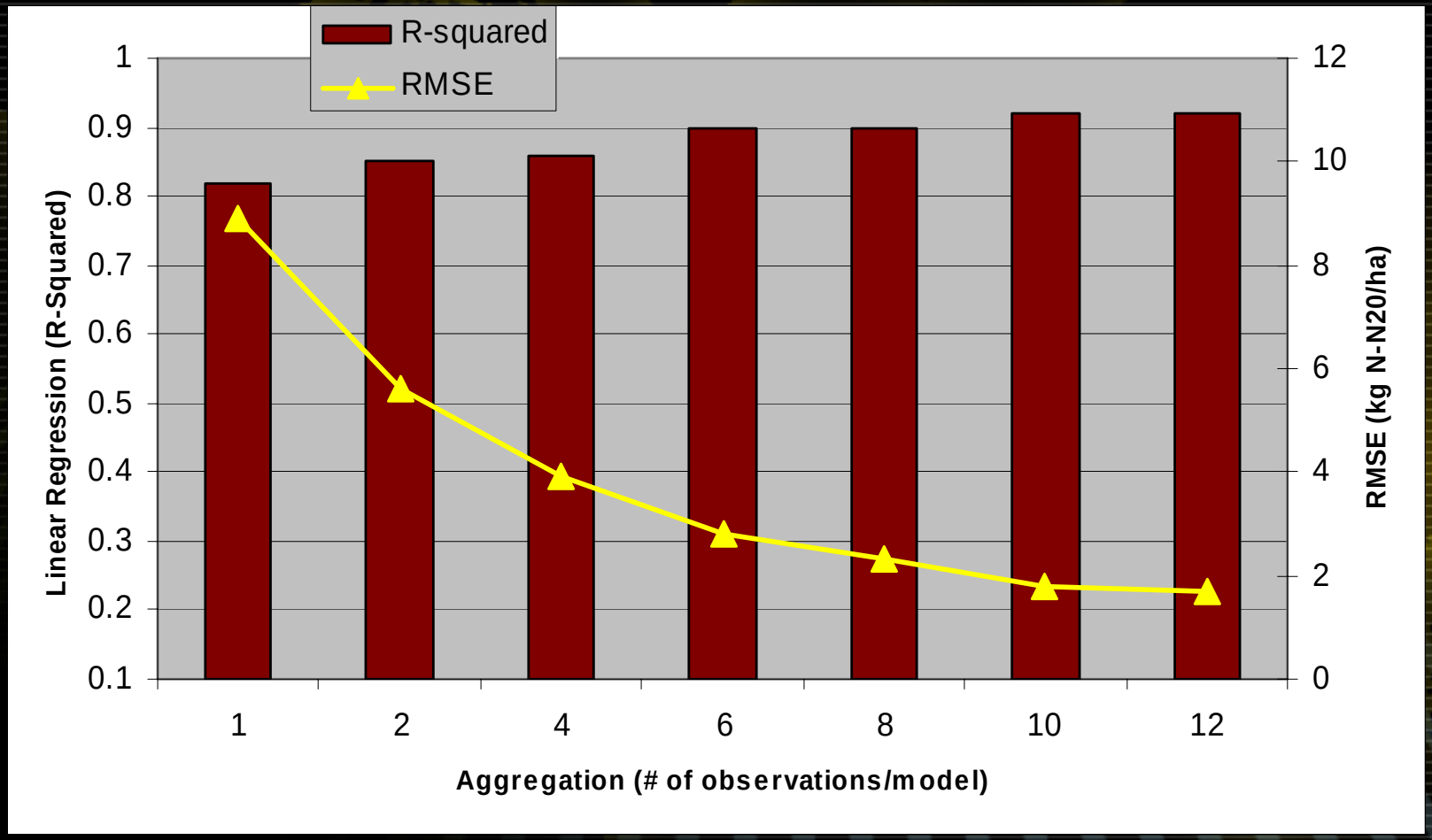
DNDC Validation



Impact of Scale: Does the model perform better when we aggregate?



Performance improves with aggregation



…implications for use in protocols and for emission inventories.

Future Validation: CA Crops

- On-going projects collecting field measurements of N2O emissions:
  - ✓ UC Davis (Horwath, Six and Smart) and CSU Fresno (Goorahoo)
  - ✓ Alfalfa, Almonds, Silage Corn, Cotton, Grapes (table and wine), Lettuce, Rice, Tomato and Walnut
  - ✓ Will create an important validation dataset for California
  - ✓ Funding from ARB, CDFA, CEC and Packard
  - ✓ Timeline: 2009 through 2012

Using Model for Mitigating GHG Emissions : Tomato Example

Site: A tomato field at SAFS site in Davis, California

Simulated period: 1991-2000

Climate: Temperature 16°C, precipitation 210-630 mm

Soil: Silt loam, SOC 0.011 kg C/kg, pH 7.0

Tillage: Conventional

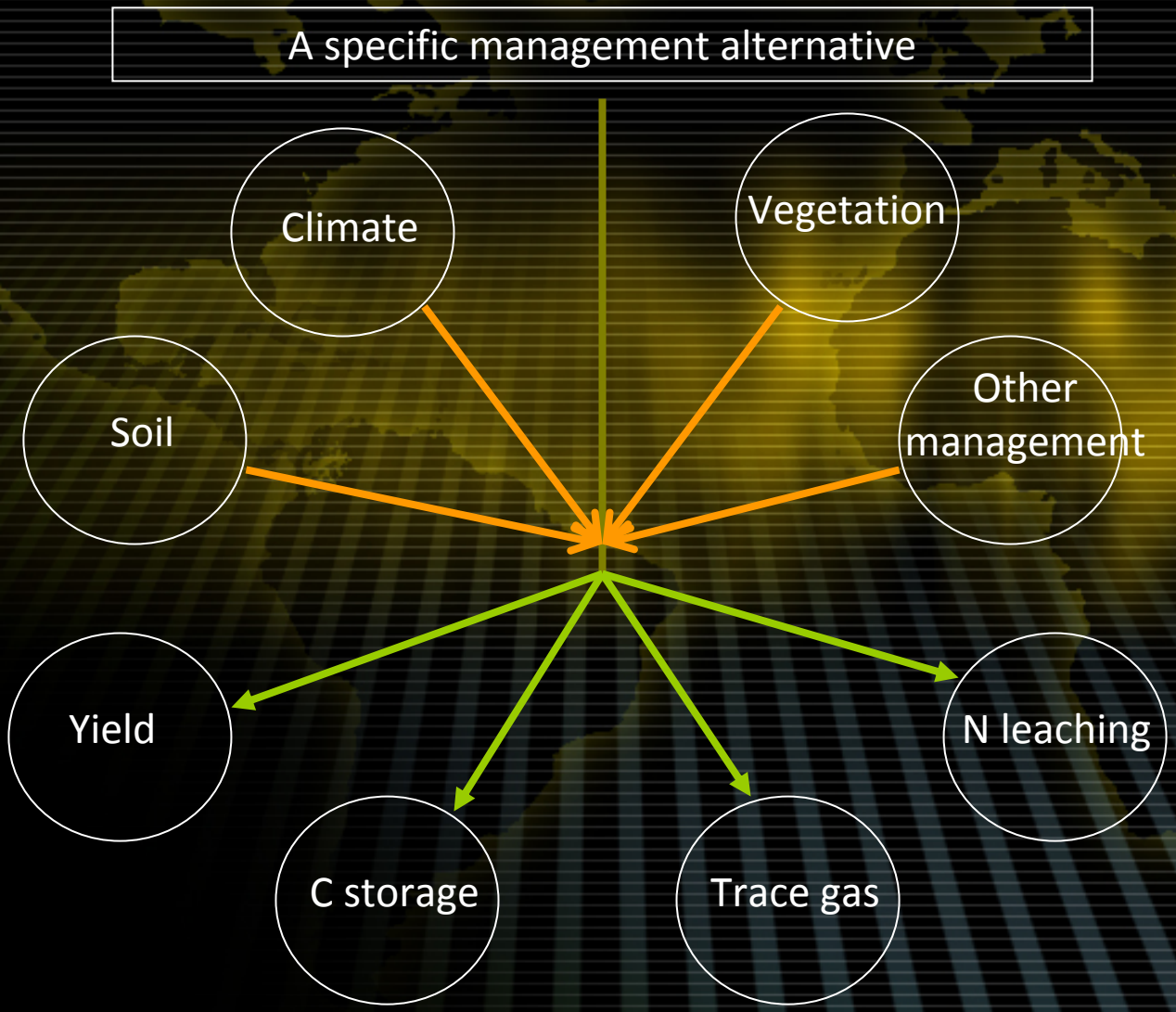
Fertilization: 150 kg urea-N/ha

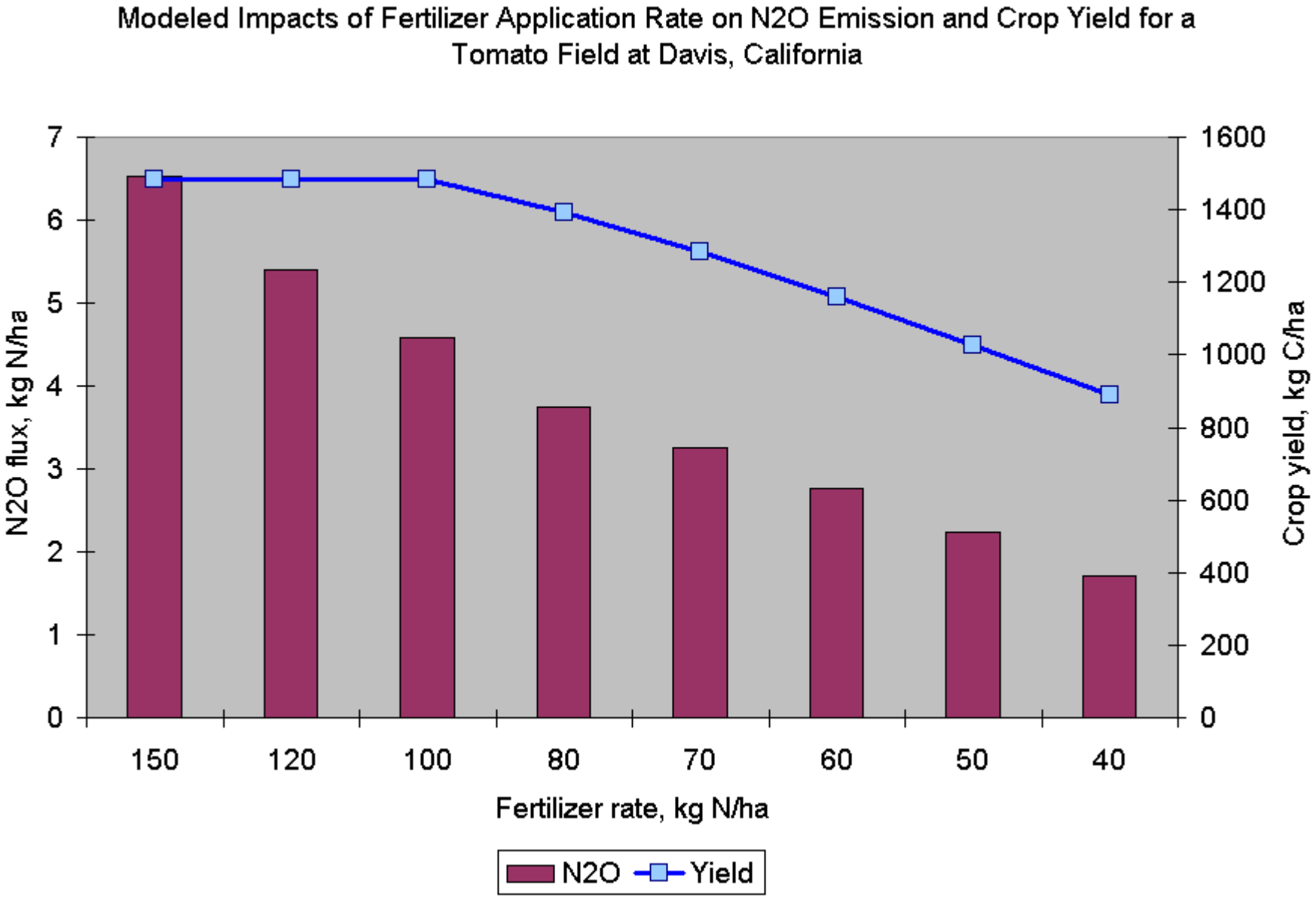
Irrigation: Precision with drip or better spray method

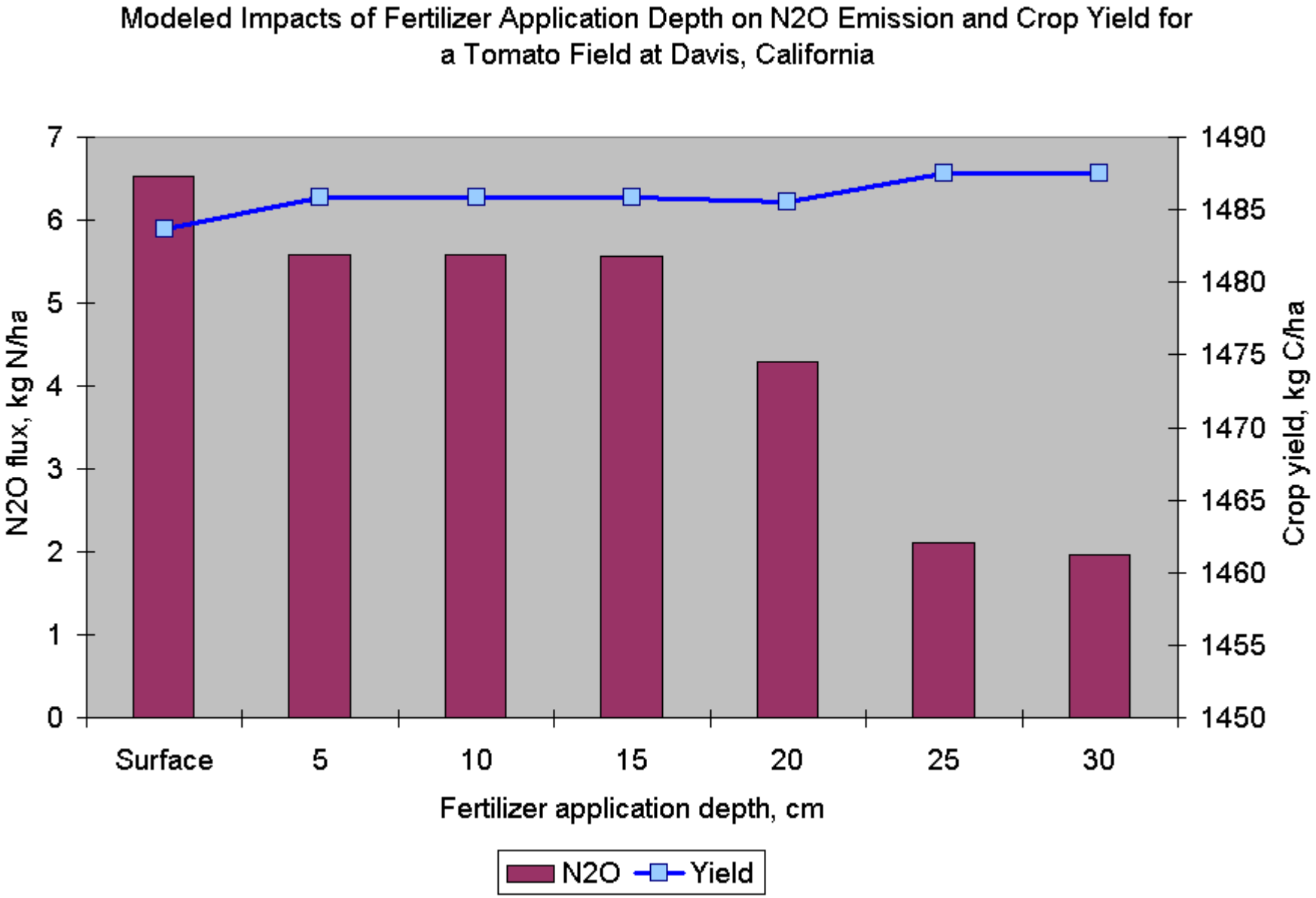
DNDC as a Decision Support Tool…

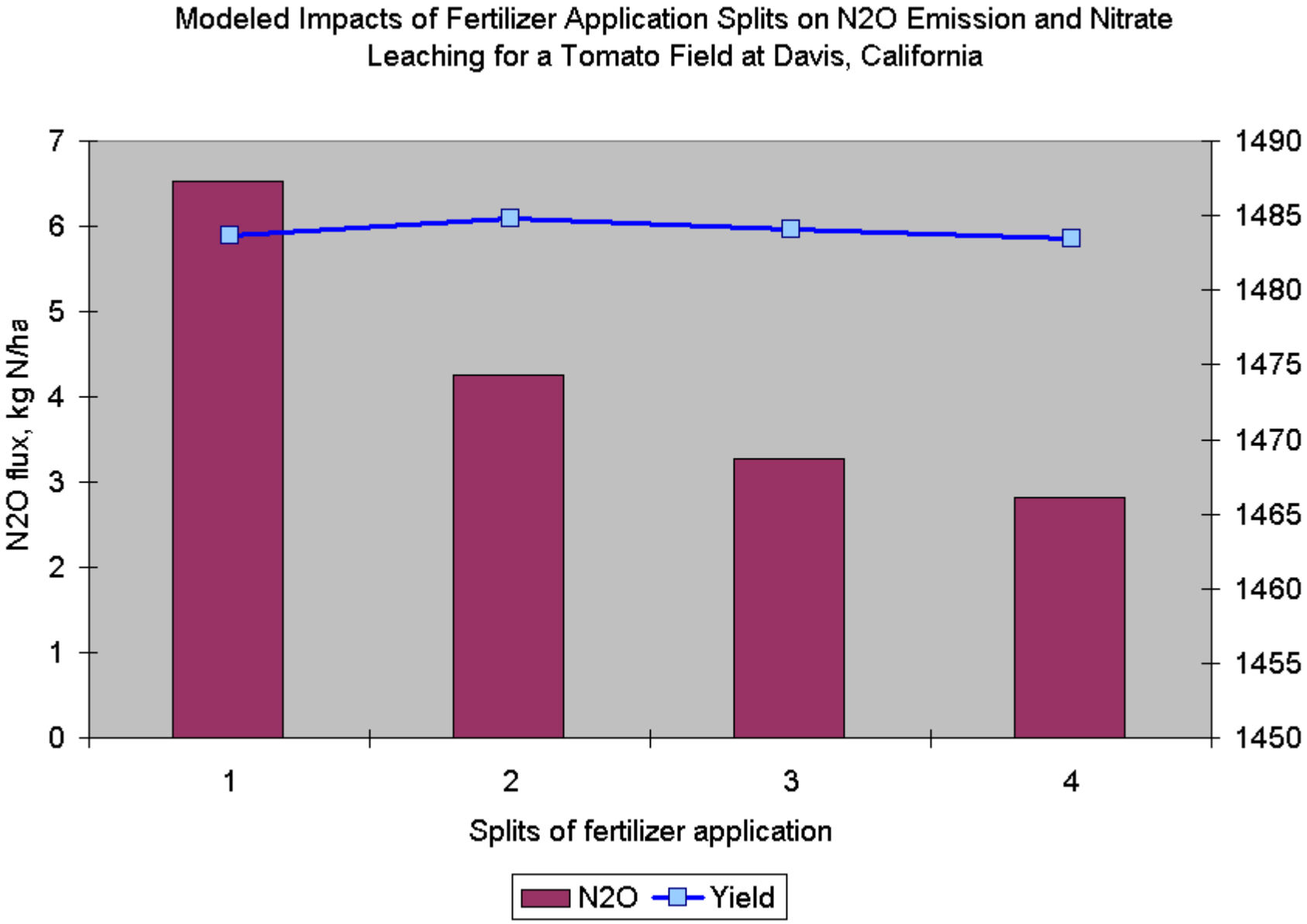
…examine fertilizer practices (rate, depth, # applications)

Biogeochemical models (DNDC) serve Applications for Defining Management Opportuntites for Mitigating GHG Emissions




Modeled Impacts of Fertilizer Application Rate on N2O Emission and Crop Yield for a Tomato Field at Davis, California
N2O flux, kg N/ha
Crop yield, kg C/ha
0
1
2
3
4
5
6
7
0
200
400
600
800
1000
1200
1400
1600
150
120
100
80
70
60
50
40
Fertilizer rate, kg N/ha
N2O
Yield


Modeled Impacts of Fertilizer Application Depth on N2O Emission and Crop Yield for a Tomato Field at Davis, California
N2O flux, kg N/ha
Crop yield, kg C/ha
0
1
2
3
4
5
6
7
1450
1455
1460
1465
1470
1475
1480
1485
1490
Surface
5
10
15
20
25
30
Fertilizer application depth, cm
N2O
Yield


Modeled Impacts of Fertilizer Application Splits on N2O Emission and Nitrate Leaching for a Tomato Field at Davis, California
N2O flux, kg N/ha
0
1
2
3
4
5
6
7
1450
1455
1460
1465
1470
1475
1480
1485
1490
1
2
3
4
Splits of fertilizer application
N2O
Yield

Impacts of Baseline vs. Management Scenarios on N_2O Emission and Other C and N Fluxes for a Tomato Field

	Baseline	BMP	Change rate
N_2O (kg N/ha)	5.9	2.7	-54%
NH_3 (kg N/ha)	4.4	2.1	-52%
N leaching (kg N/ha)	56	21	-63%
Crop yield (kg DM/ha)	3718	3710	-0.2%
dSOC (kg C/ha)	-1470	-1472	+0.1%

Discussion: Tomato Example

1. N_2O emissions from agricultural soils can be reduced by up to 50% by adopting alternative fertilizing approaches;
2. Effectiveness of the alternatives varies with climate, soil and other management conditions (use GIS data as inputs);
3. Integrated model-database tool can be integrated with other tools for spatially differentiated Carbon footprints and assessment of mitigation options.

California rice case study:

Using DNDC for GHG inventory and assessing opportunities for reducing GHG emissions.

NRCS, EDF and CRC Funding
PIs: Eric Holst (EDF) and Paul Buttner (CRC)
Collaboration with UC Davis

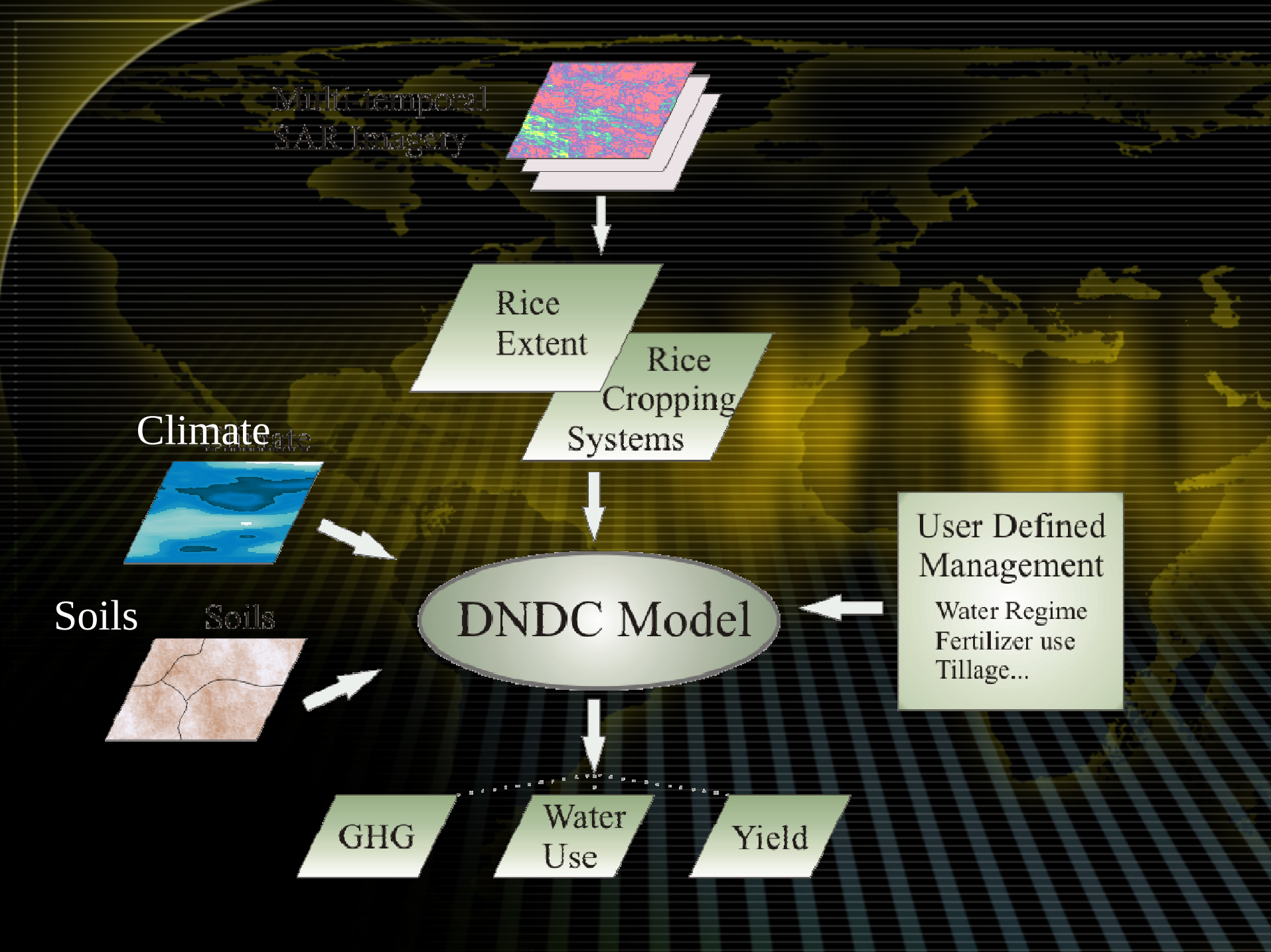
Project Goals:

- Use DNDC to define baseline net Greenhouse Gas Emissions
  - Baseline refers to current management practices, namely rice production during summer months with continuous flooding, followed by straw residue incorporation with winter flooding.
- Use DNDC to assess opportunities for net GHG emission reductions through changes in residue, water and/or fertilizer management.
- Define protocol for carbon offsets.

Background: GHG from Rice

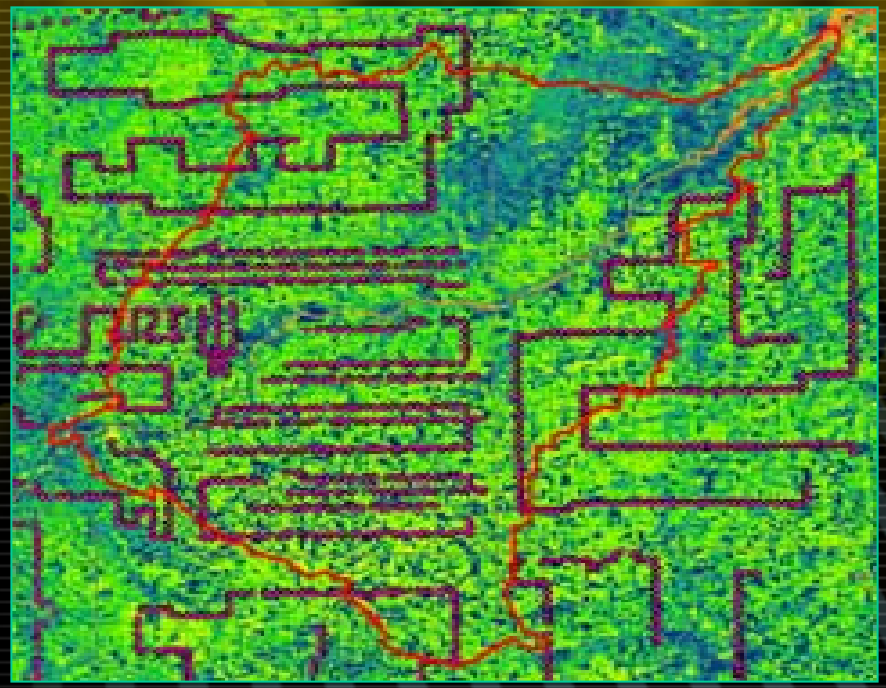
- Methane (CH4) – produced by fermentation in anaerobic conditions (flooding), GWP = 25 (25 times more potent than CO_2)
  - Dominant GHG in continuously flooded rice.
- Nitrous Oxide (N2O) –produced by nitrification and denitrification (nitrate reduction), GWP = 298.
  - Minor GHG in continuously flooded rice
- Carbon Dioxide (release of stored soil carbon – tillage) and soil carbon sequestration (storage of organic carbon in soils – crop residues).

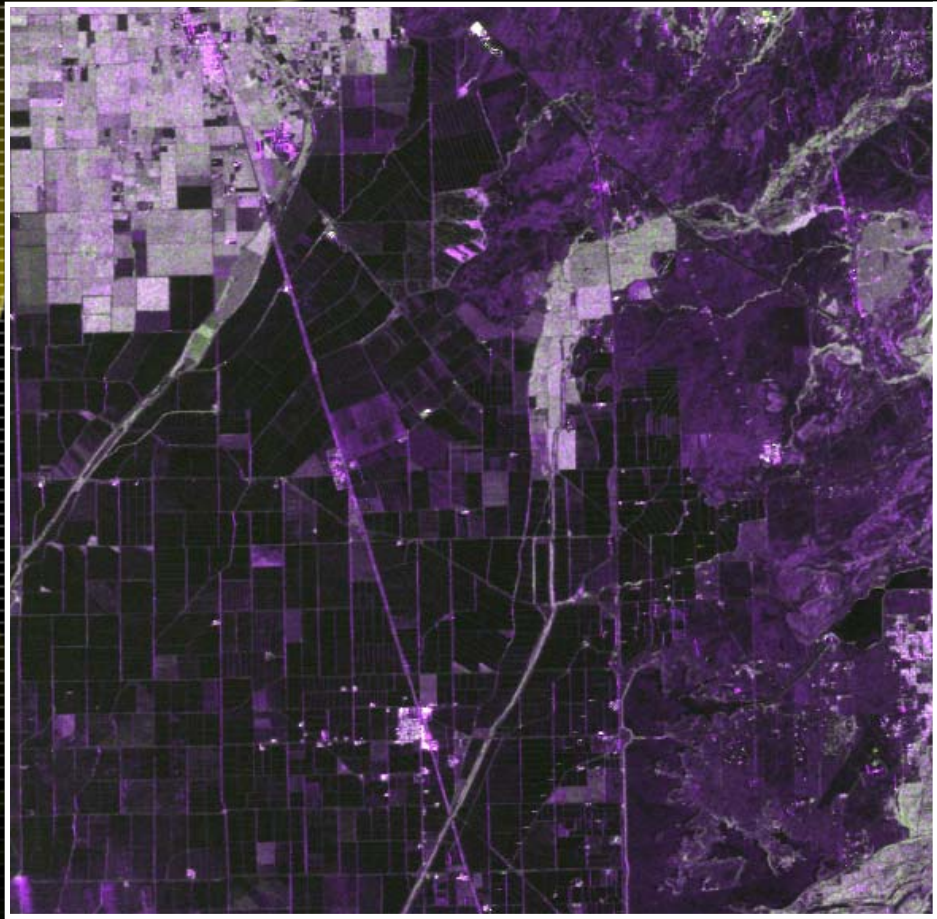
Step 1:
Use GIS and Remote Sensing to Build GIS databases for California, USA

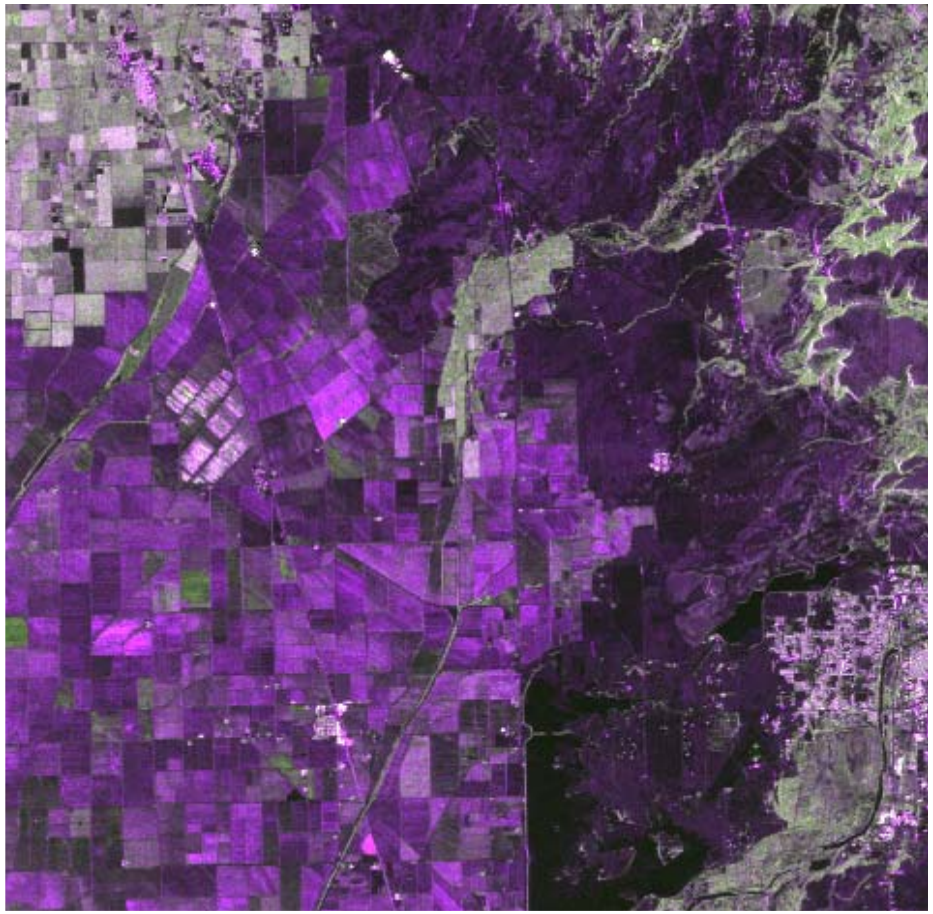

Multi-temporal
SAR Imagery
Rice
Extent
Rice
Cropping
Systems
Climate
Soils
DNDC Model
User Defined
Management
Water Regime
Fertilizer use
Tillage...
GHG
Water
Use
Yield

Agricultural Management Mapping

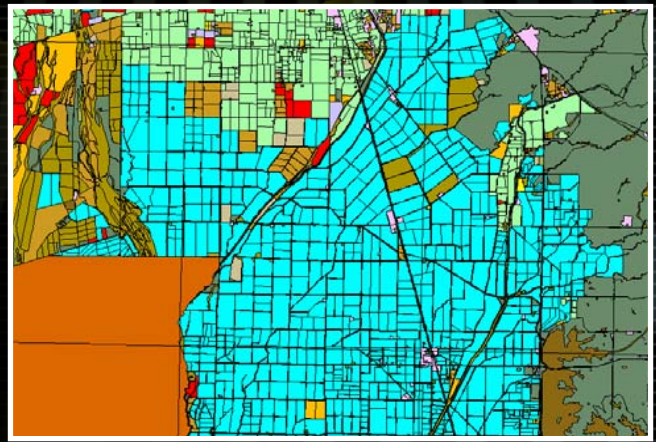
- Crop type
- Irrigation management
- Crop calendar
  - o Multi-temporal acquisition strategies enable mapping activity (planting, harvest, flooding, tilling…) dates
- Tillage practice
  - o Operational tillage mapping uses prior year (season) crop type and residue information in a decision tree framework to map tillage management







June fine beam
RGB (hh: hv: difference)

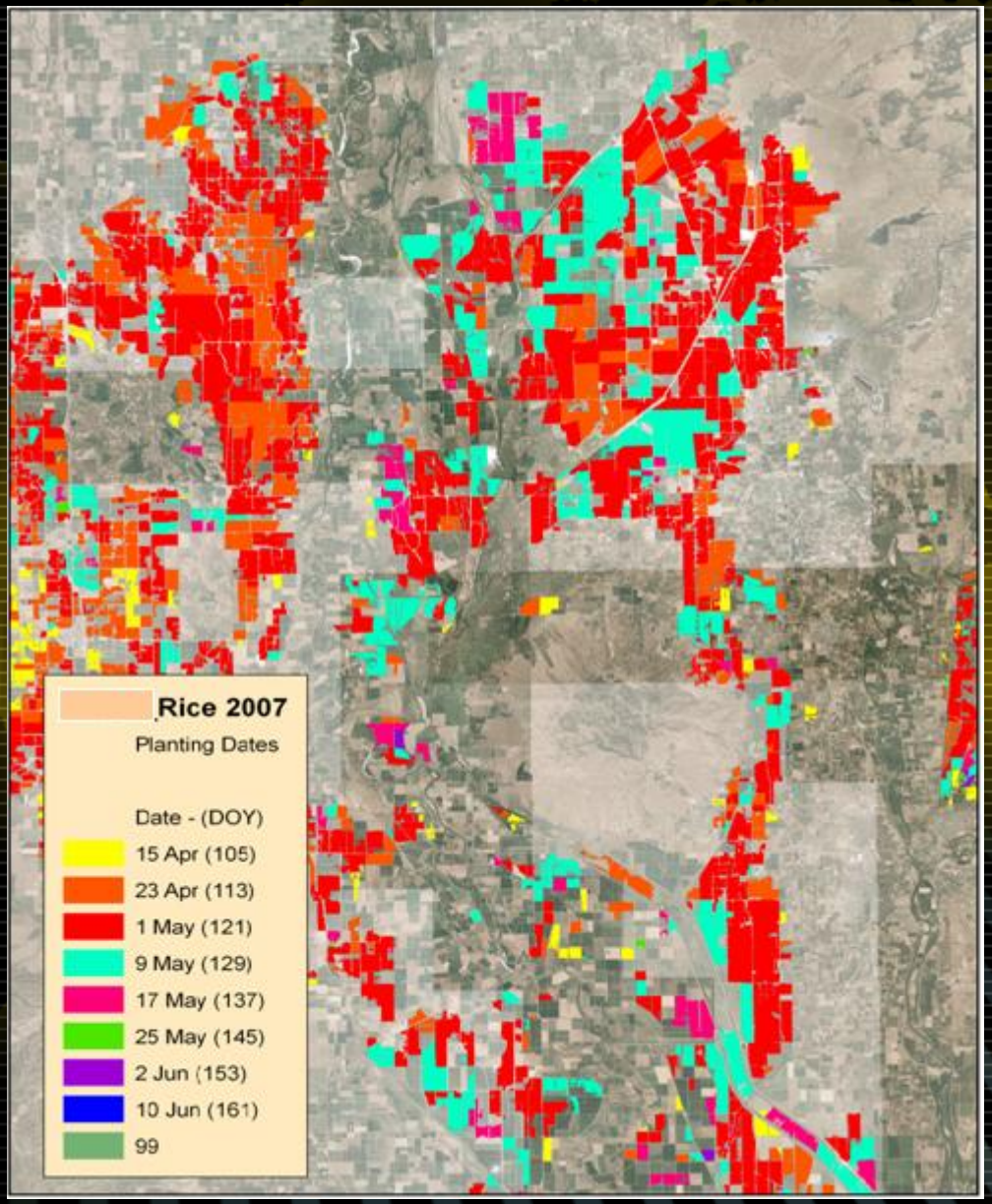


September fine beam
RGB (hh: hv: difference)

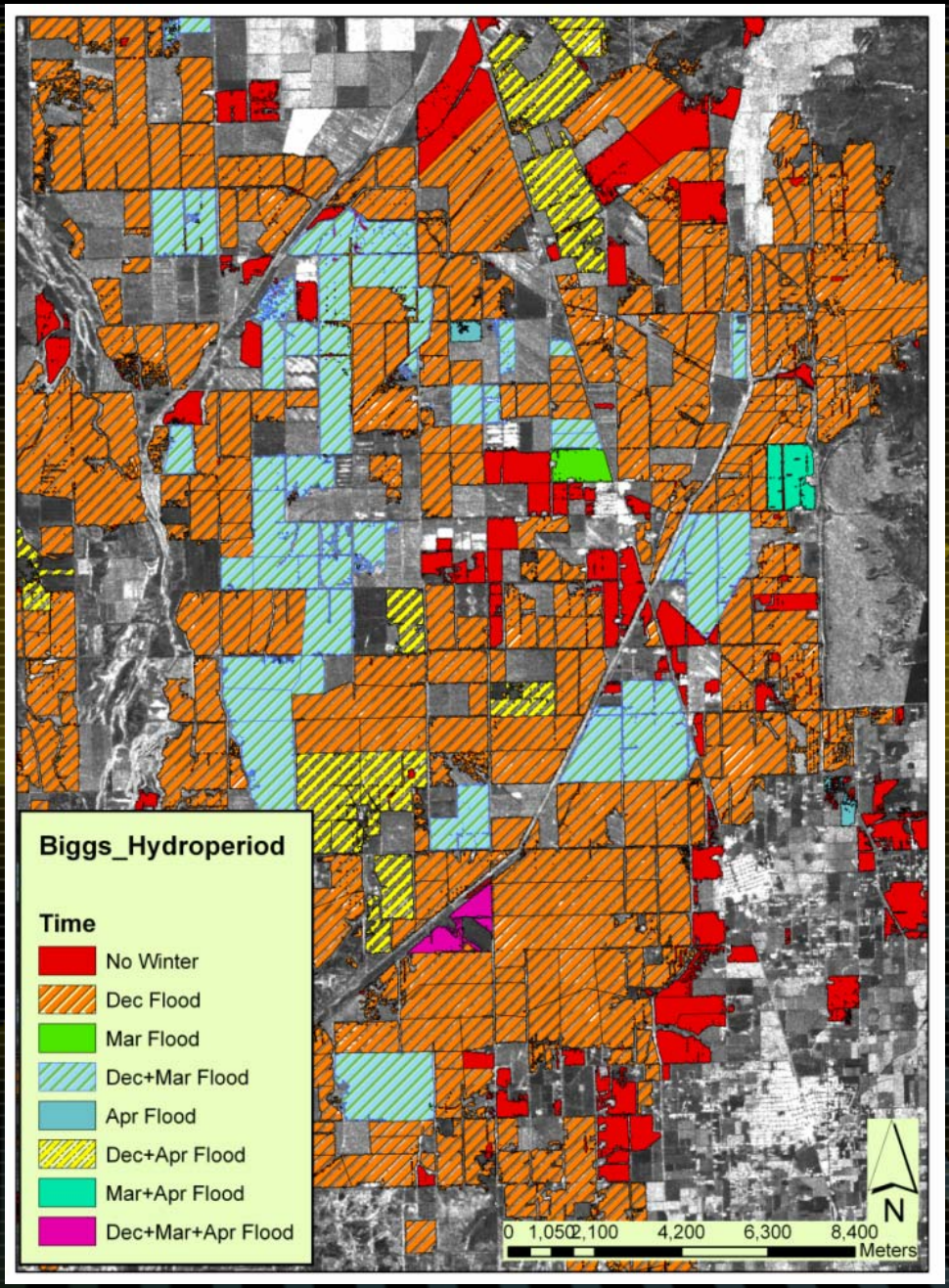
GIS LULC
Rice: turquoise, Green: fruit trees

Operational rice products
- Hydroperiod
- Crop calendar (DOY)
- Planting dates
- Parameterize models

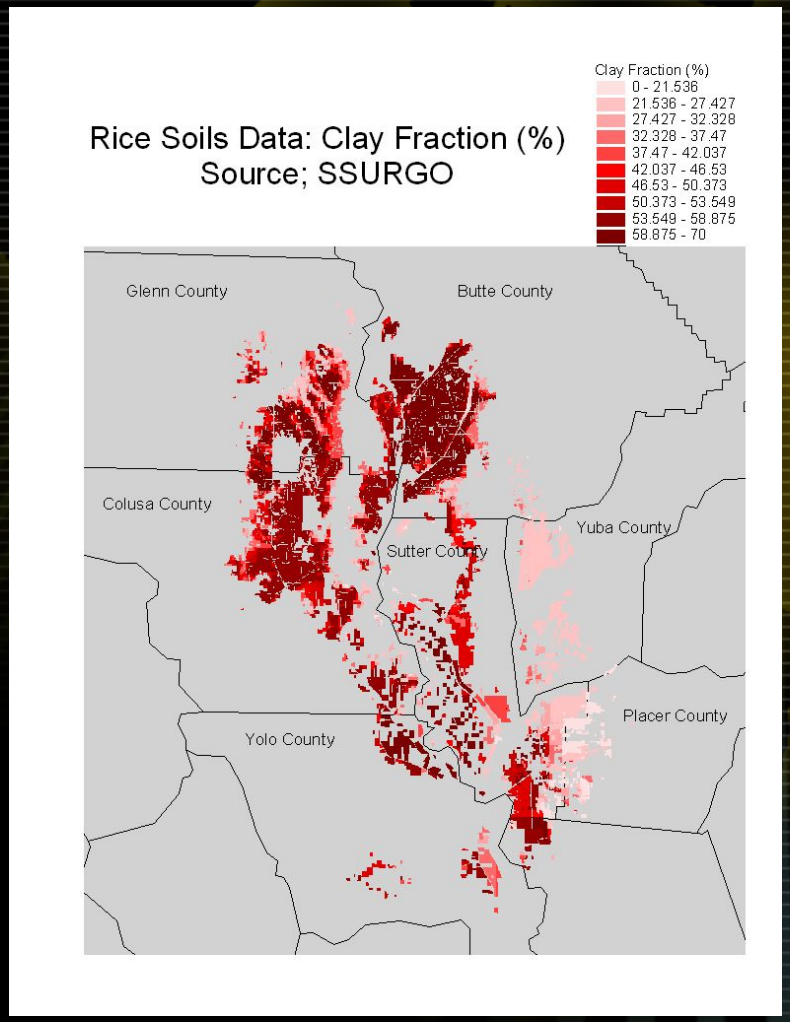
Features
- “now-cast” ability; fully automated
- 95%+ accuracy
- multiscale (spatial & temporal)
    - 6.25 m seasonal (PALSAR)
    - Moderate (Landsat/AWiFS)
    - 250m daily (MODIS)
    - 250m 8-day (MODIS)

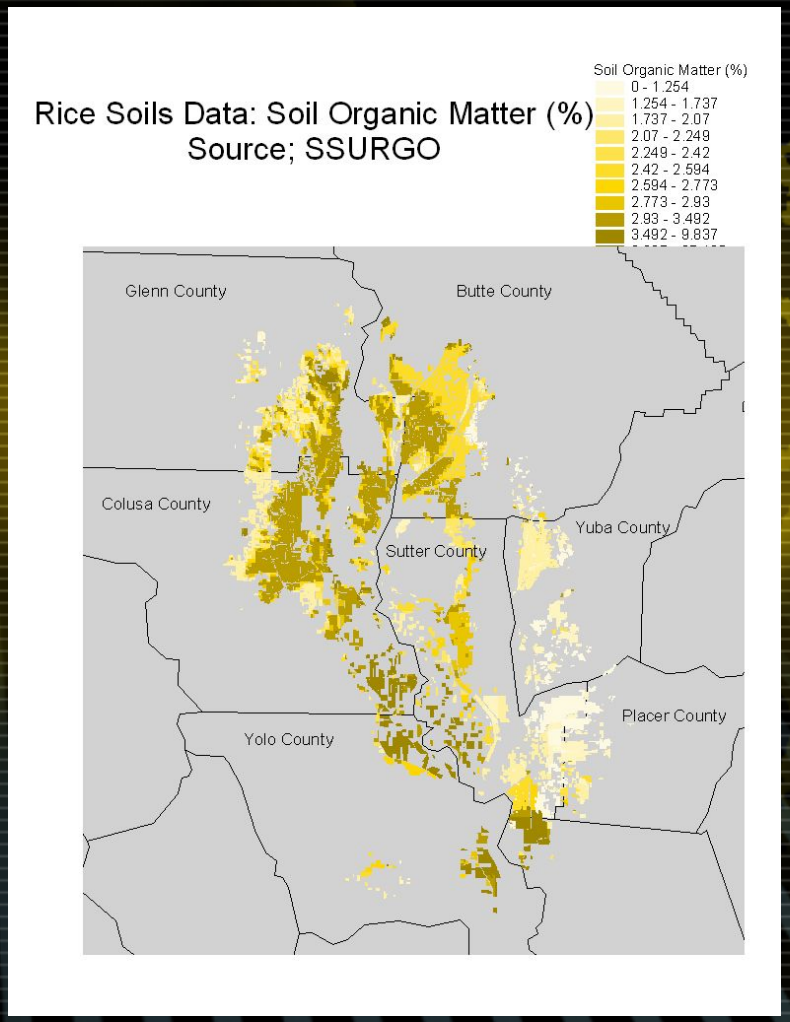


- Used Remote Sensing (PALSAR and MODIS) to map rice extent and water management – indentify baseline management.
- ~230,000 ha of rice (~500,000 acres)
- Mapped duration of winter flooded
  - -few fields had standing water in April (likely due to precipitation)



GIS Soils Databases

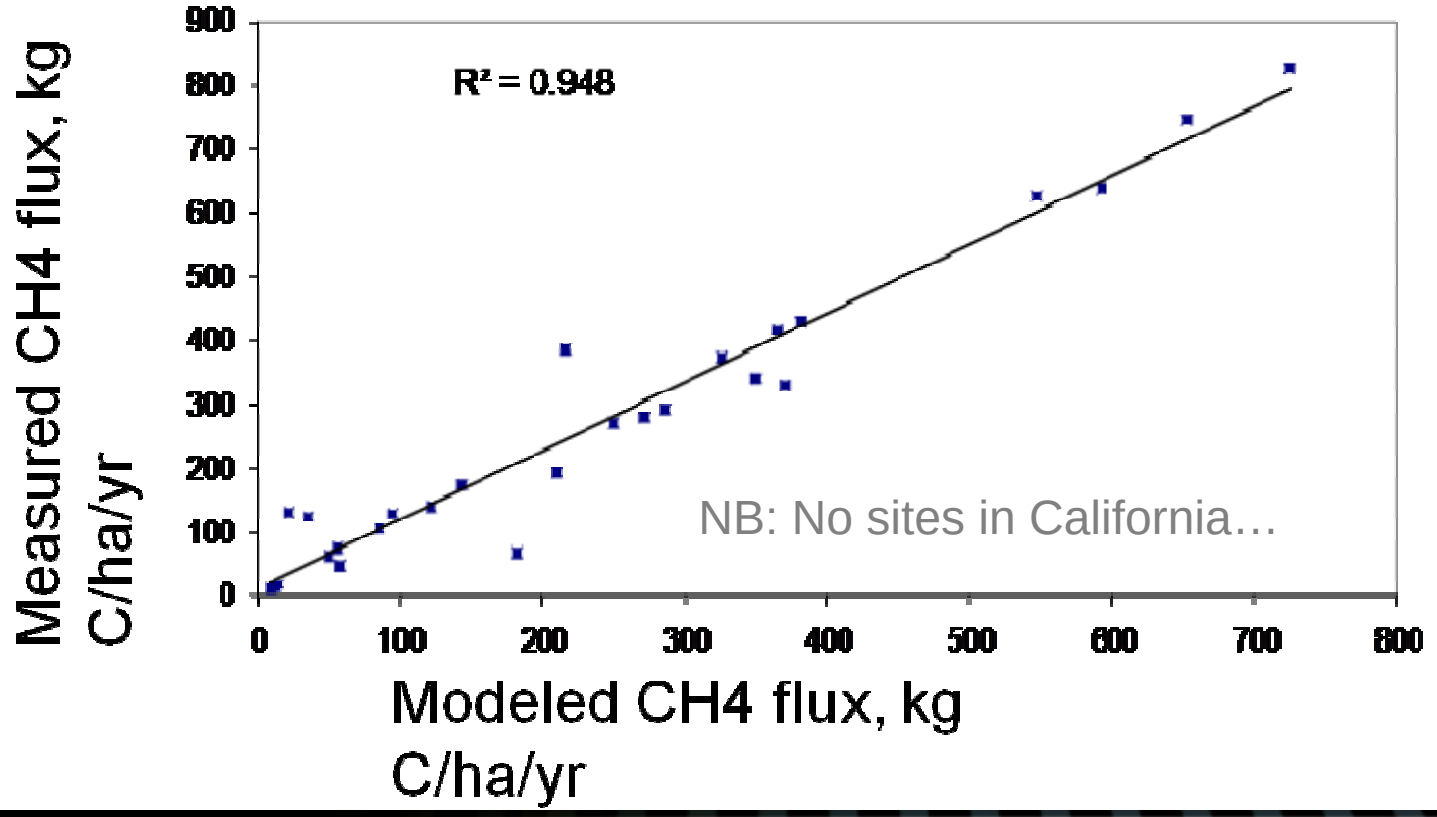




Step 2:
DNDC Model Testing for Methane from California Rice

CH4 Model Validation: Rice

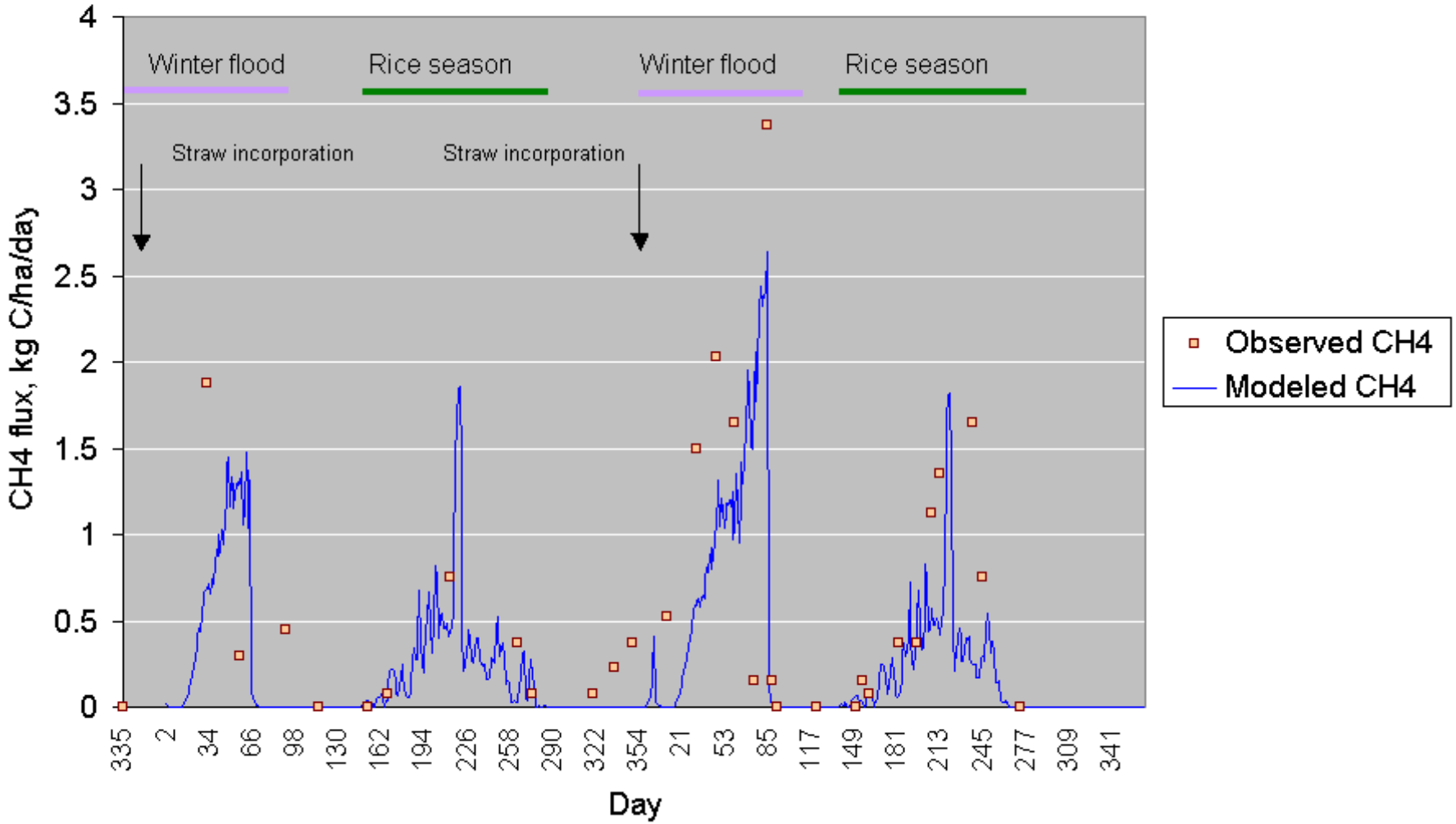
Observed and DNDC-modeled CH4 fluxes from rice paddies in China, Thailand, Japan, Italy and the U.S.



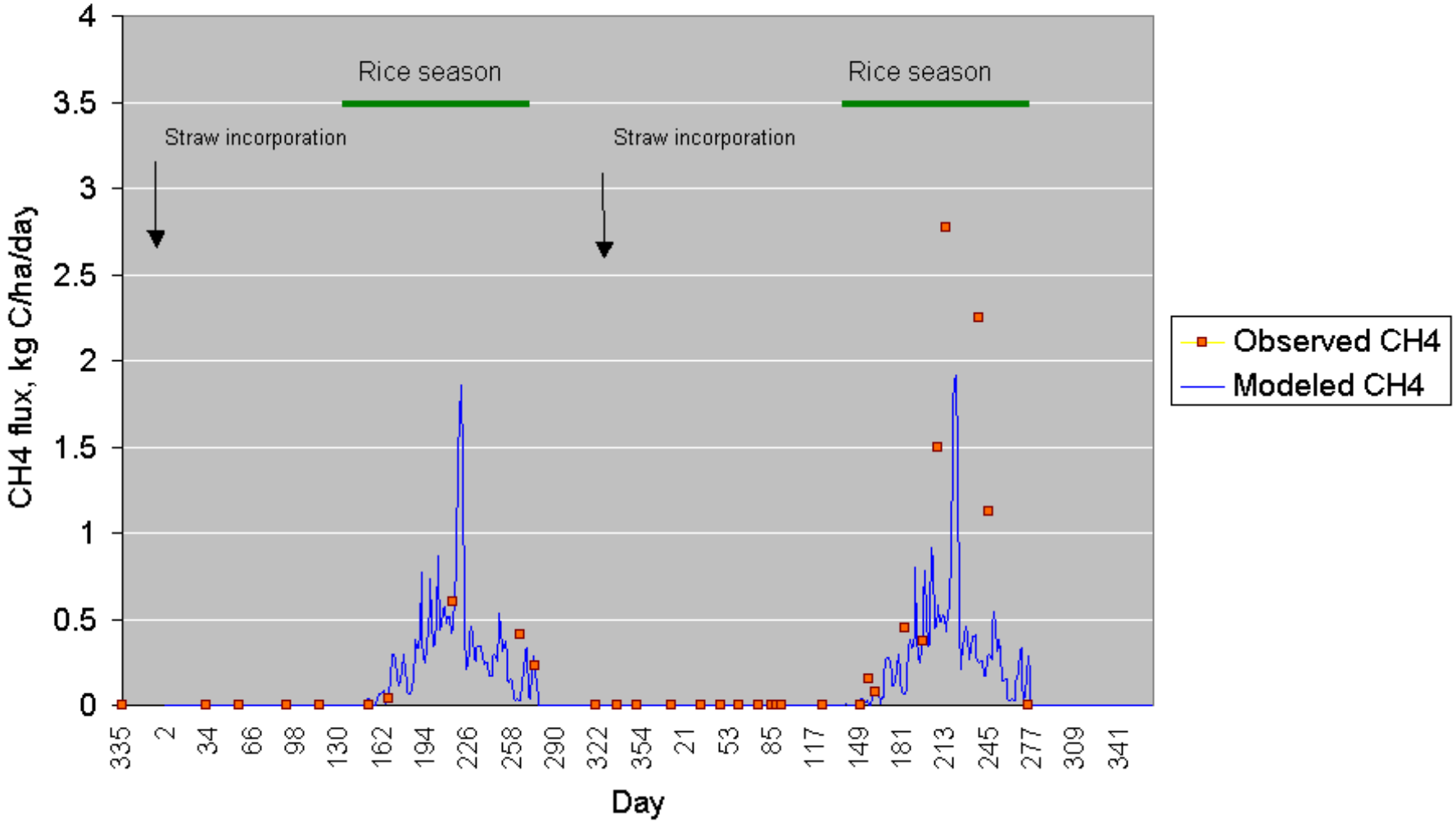
Model Testing: Maxwell & RES

- Tested DNDC against published data from a water management and residue management study at Maxwell, California.
- New data collected by Assa and Horwath at RES
- Validation data: CH4 emissions
  - Baseline management: straw incorporation with winter flooding for decomposition
  - Removal (burning) of straw residue with winter flooding
  - Incorporation of straw without winter flooding
  - Drill seeding

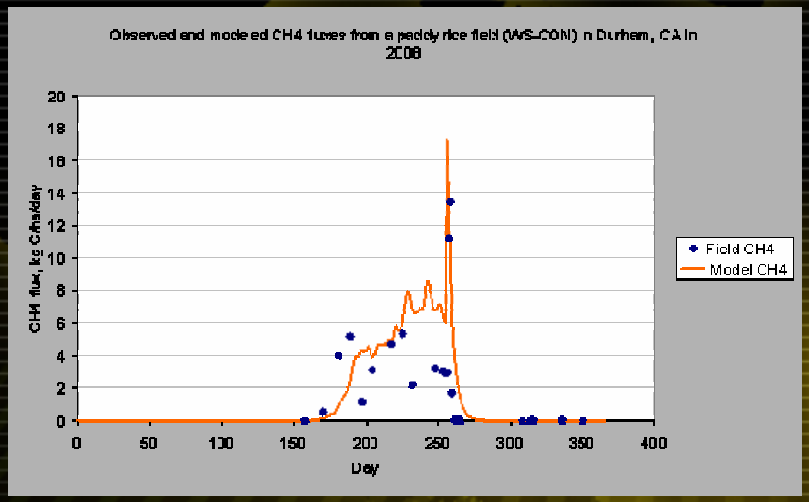
Observed and DNDC-modeled methane fluxes from a paddy rice field with winter flood and straw incorporation in Maxwell, California 1994-1996

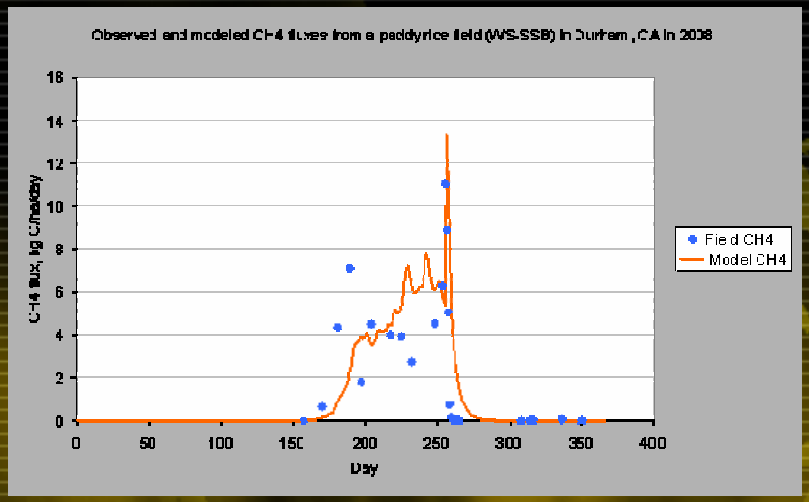


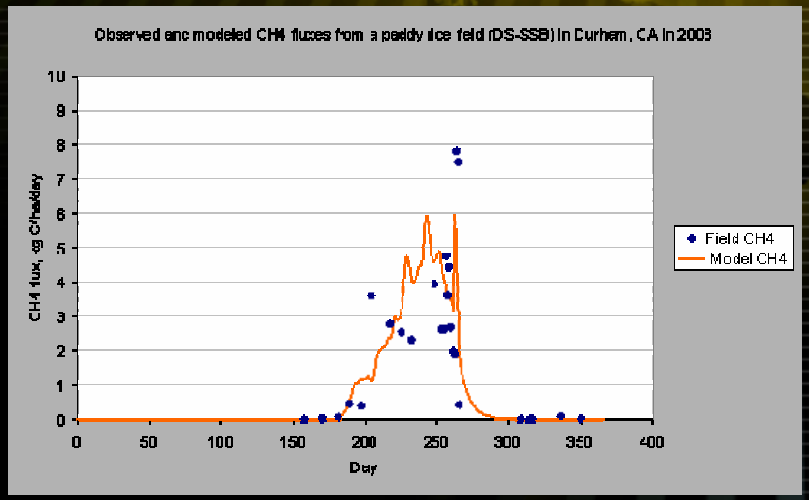
Observed and DNDC-modeled methane fluxes from a paddy rice field with straw incorporation but no winter flood in Maxwell, California 1994-1996

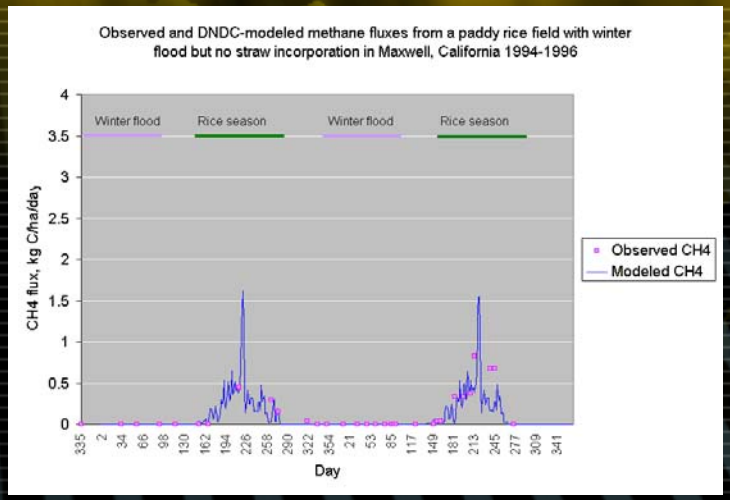


Additional Rice Methane validation data for California





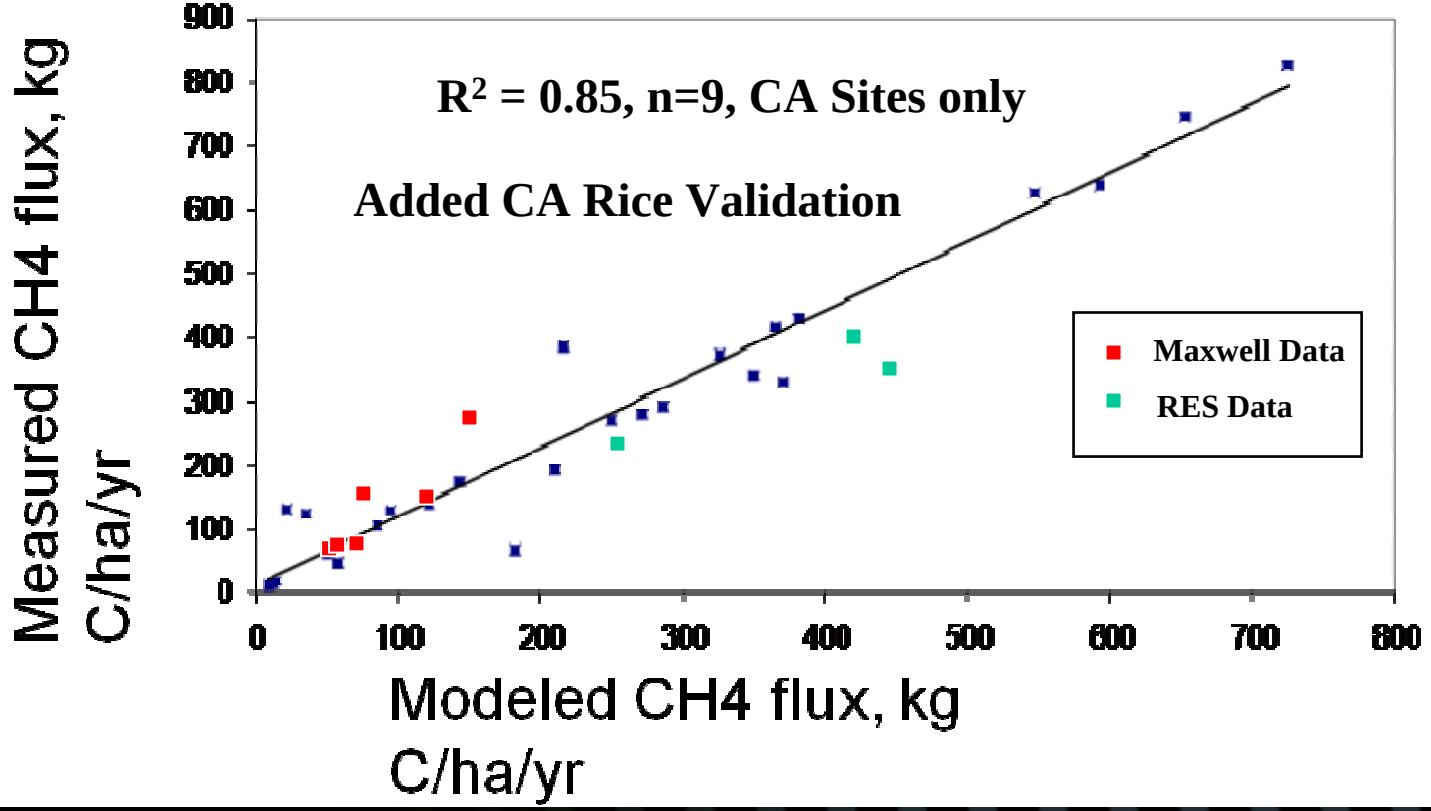




RES data: source Assa and Horwath, unpublished

CH4 Model Validation: With CA Sites

Observed and DNDC-modeled CH4 fluxes from rice paddies in China, Thailand, Japan, Italy and the U.S.



Step 3:
Run DNDC Model for Baseline and Candidate Offset Management Practices for California, USA

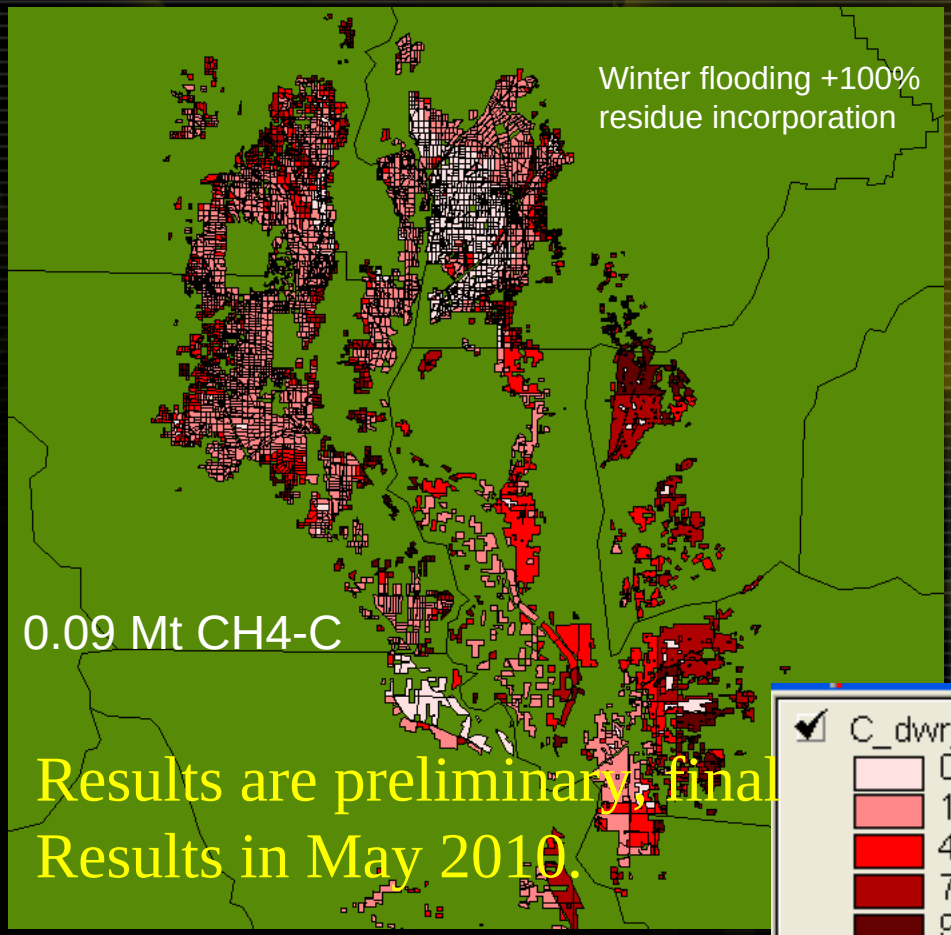
Rice Straw and Flooding Management

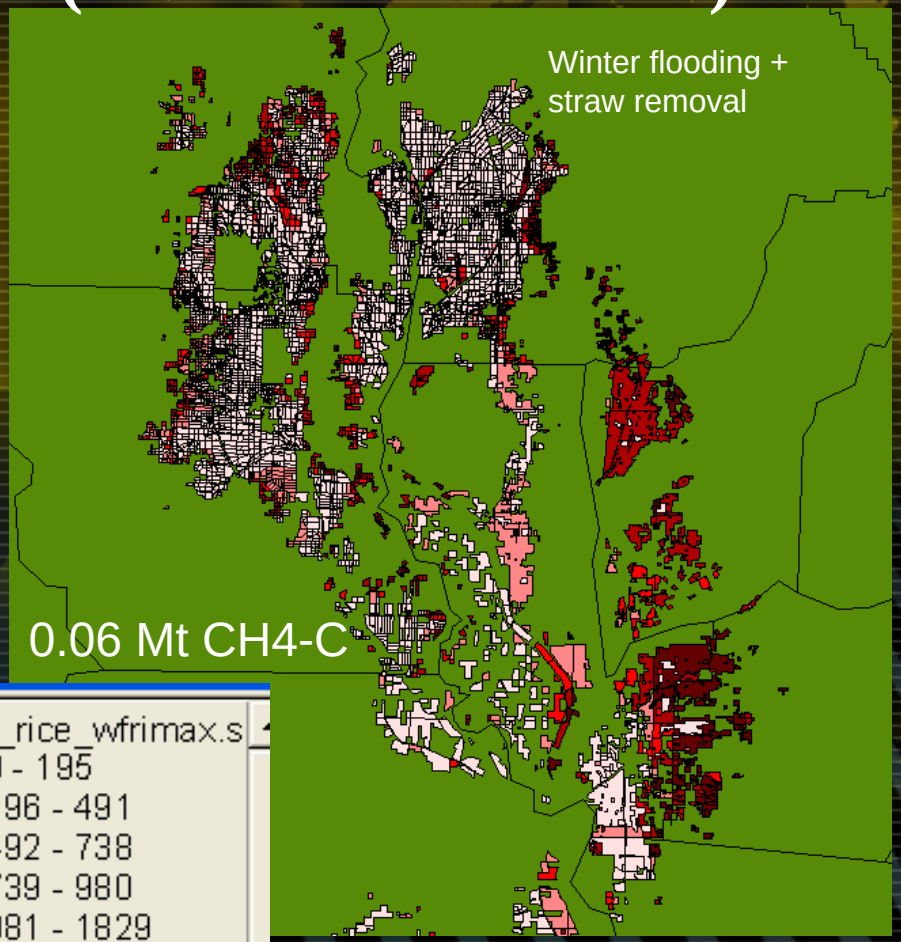
- Baseline Management (current typical practices)
  - ✓ Water seeded, rice straw incorporated (15% burned), winter flooded (50-70%), tillage and fertilizer use (based on UCCE stats).
- Alternative management to reduce GHG
  - ✓ Straw removal
  - ✓ No winter flooding
  - ✓ Mid-season drainage
  - ✓ Drill seeding

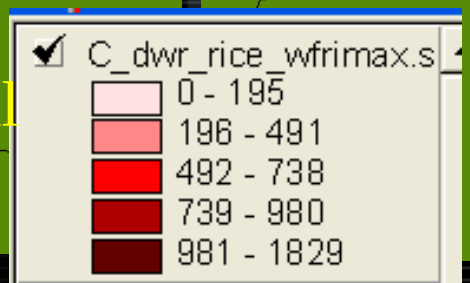
Baseline and Straw Removal Results:

Spatially explicit DNDC-modeled CH4 emissions from CA rice fields with different water/residue management practices in 2004

- **Baseline emissions (~0.09 MMT CH4-C)**
- **Straw removal emissions (~0.06 MMT CH4-C)**





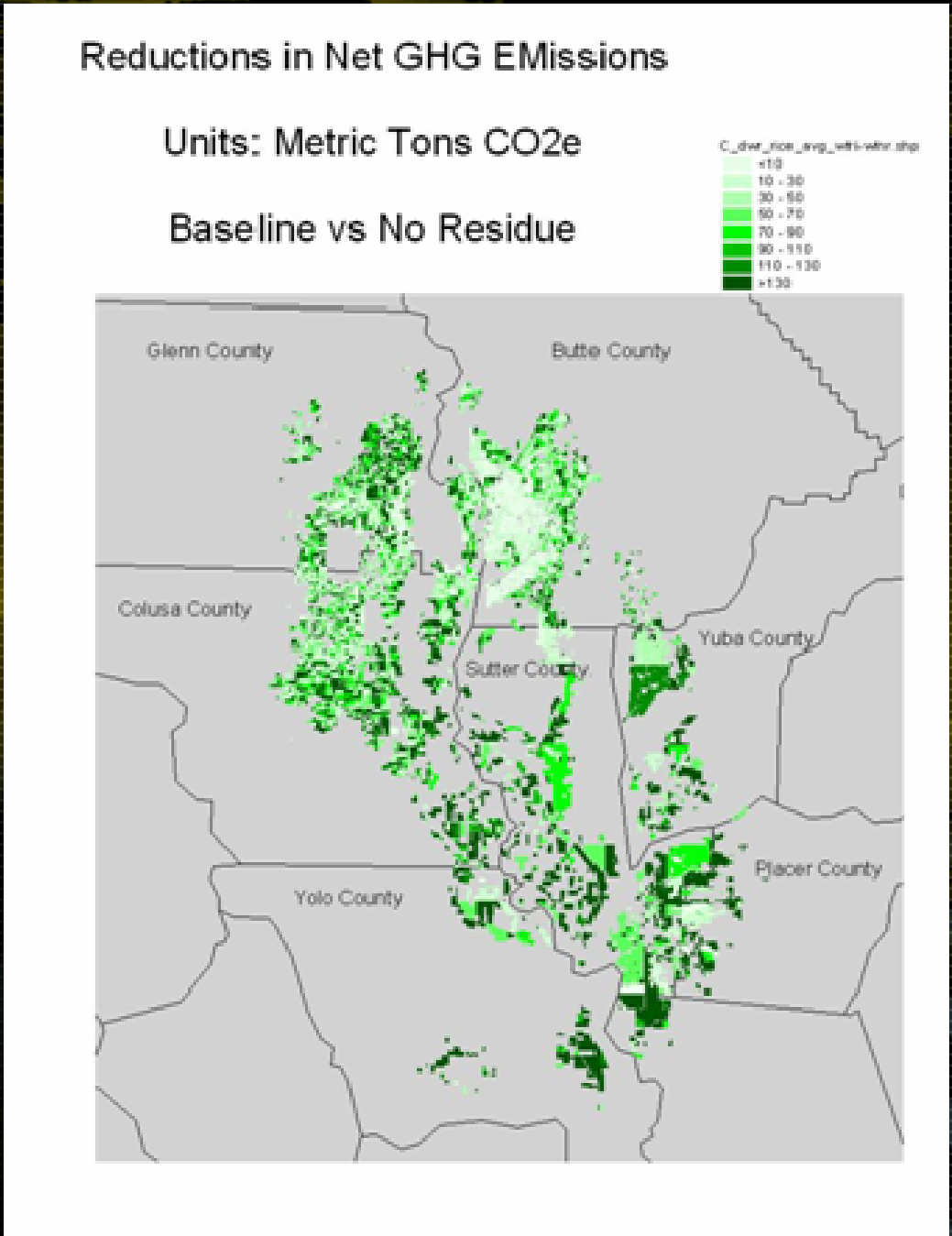


Results are preliminary, final Results in May 2010.

GHG Reductions

Spatial Variability

Power of process model to capture spatial variability in environmental controls on Ch4 emissions.



Methane Emissions from Rice: Comparison of Methods

- US EPA Emission Factor: 210 kg CH4/ha/yr
- ARB Emission Factor: 122 kg CH4/ha/yr
- DNDC Model: ~500 Kg CH4/ha/yr

Source of discrepancies?

CA Maxwell site has heavy soils (50% clay) and thus low emissions ~170 kg CH4/ha)

EFs do not include Winter flooding

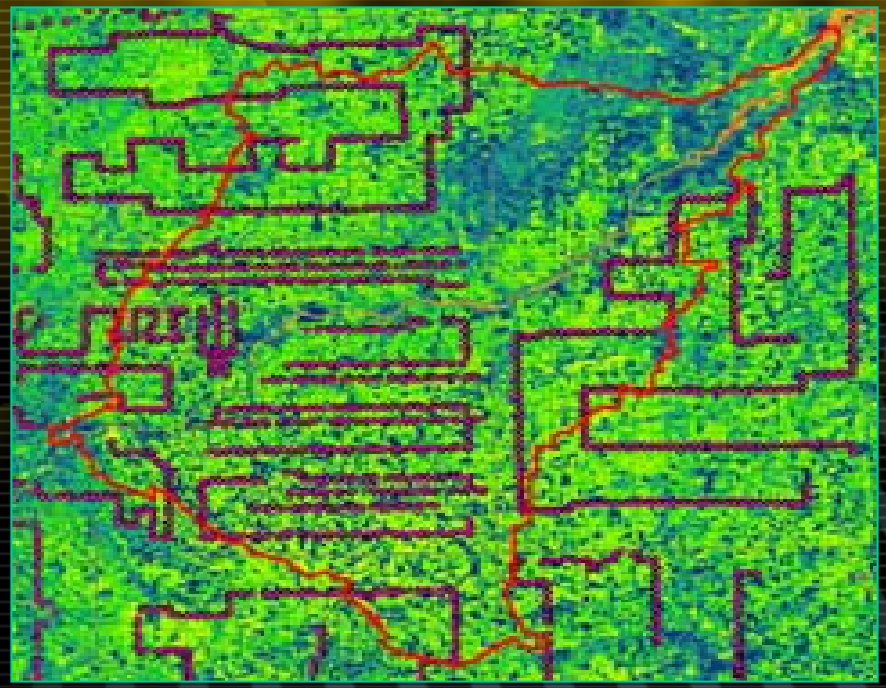
RES data (~450 kg CH4/ha, source: Assa and Horwath, unpublished)

Role of Remote Sensing…

Important for developing regional databases and for mapping and potentially monitoring management practices: for compliance, verification , or tracking sustainability…

Agricultural Management Mapping

- Crop type
- Irrigation management
- Crop calendar
  - o Multi-temporal acquisition strategies enable mapping activity (planting, harvest, flooding, tilling…) dates
- Tillage practice
  - o Operational tillage mapping uses prior year (season) crop type and residue information in a decision tree framework to map tillage management



Web-based Geospatial Tillage Mapping and Monitoring System

In development with NASA and USDA funding

Wood County, OH (Maumee River Watershed)
23 May, 2006

R: SWIR, G: NIR, B: RED; Landsat TM 5

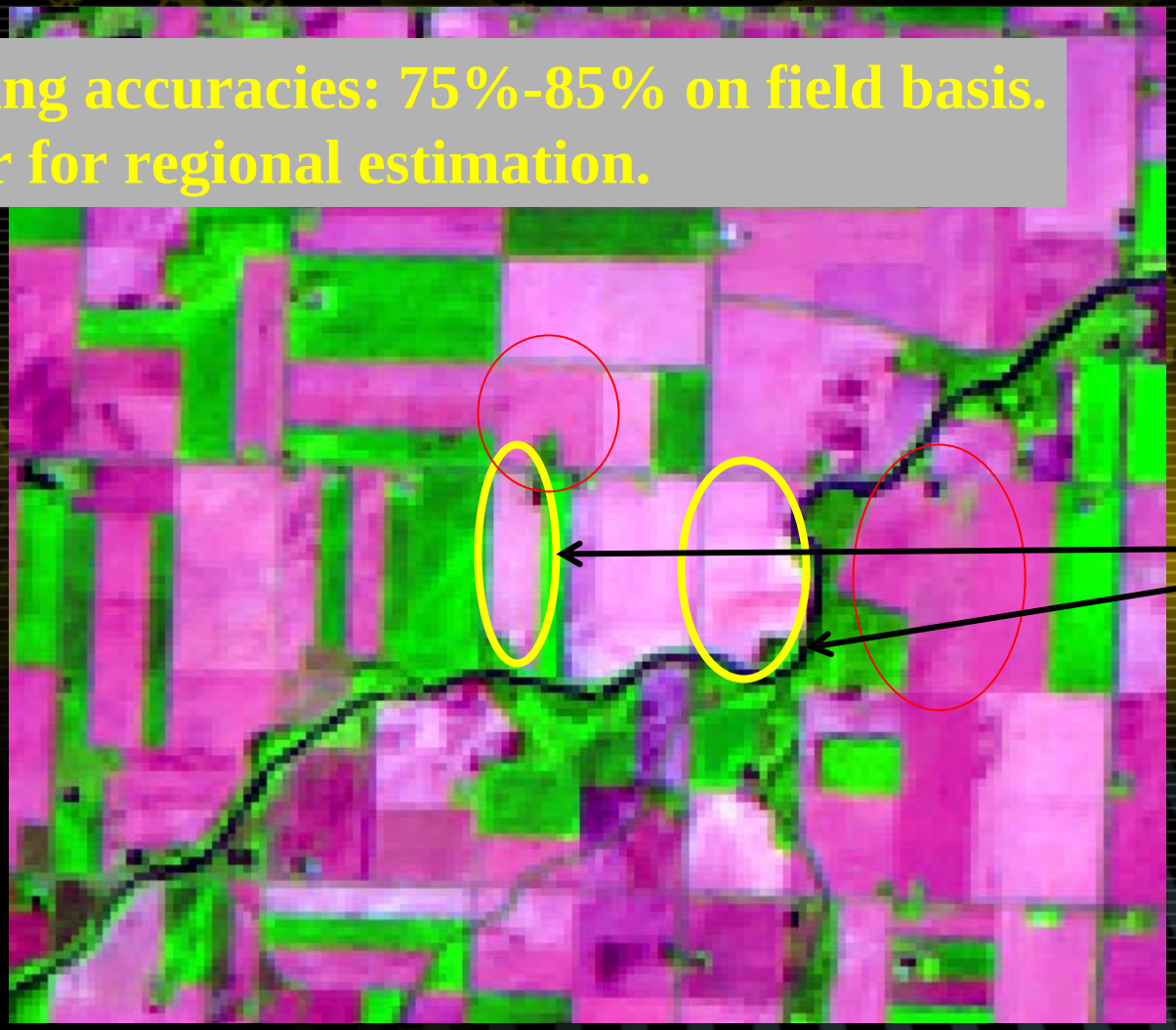
Wood County, OH (Maumee River Watershed)
23 May, 2006

High Crop Residue Cover
Corn – No Till

R: SWIR, G: NIR, B: RED
Landsat TM 5

Wood County, OH (Maumee River Watershed)
23 May, 2006

Mapping accuracies: 75%-85% on field basis. Higher for regional estimation.



Low Crop Residue Cover
Soy – Conventional Till

R: SWIR, G: NIR, B: RED
Landsat TM 5

Conclusions…

- CH4 and N2O emissions from agricultural is a complex, driven by environmental condition, management and microbial processes
- Process models are critical tools for developing GHG inventories and assessing options for reductions
- Rigorous validation is key…must rely on sound field measurements.
- Remote sensing has an important role for mapping and monitoring.
- Tools for tracking uncertainty: model structural and due to uncertainties in input conditions.

Thank you!

Dr. William Salas
Applied Geosolutions, LLC
87 Packers Falls Road
Durham, NH 03924 USA
wsalas@agsemail.com