Minerals Management Service
Information Transfer Meeting
Gas Hydrate Resource Evaluation
U.S. Outer Continental Shelf

Matt Frye

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Independence Hub photo courtesy Anadarko Petroleum Corp.

7 January 2009

Talk Outline

- **What is Gas Hydrate ?**

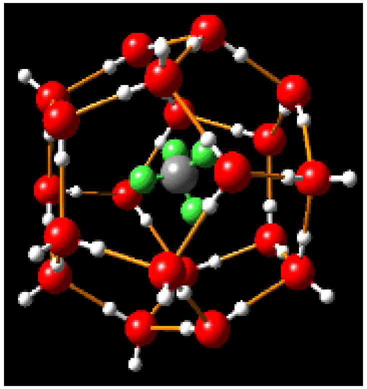
- **Interagency Efforts**
  - → Joint Industry Project (JIP)

- **MMS Gulf of Mexico (GOM) Gas Hydrate Assessment**
  - → Background / Project Goals
  - → GOM Regional Geology
  - → Model methodology
  - → In-Place results

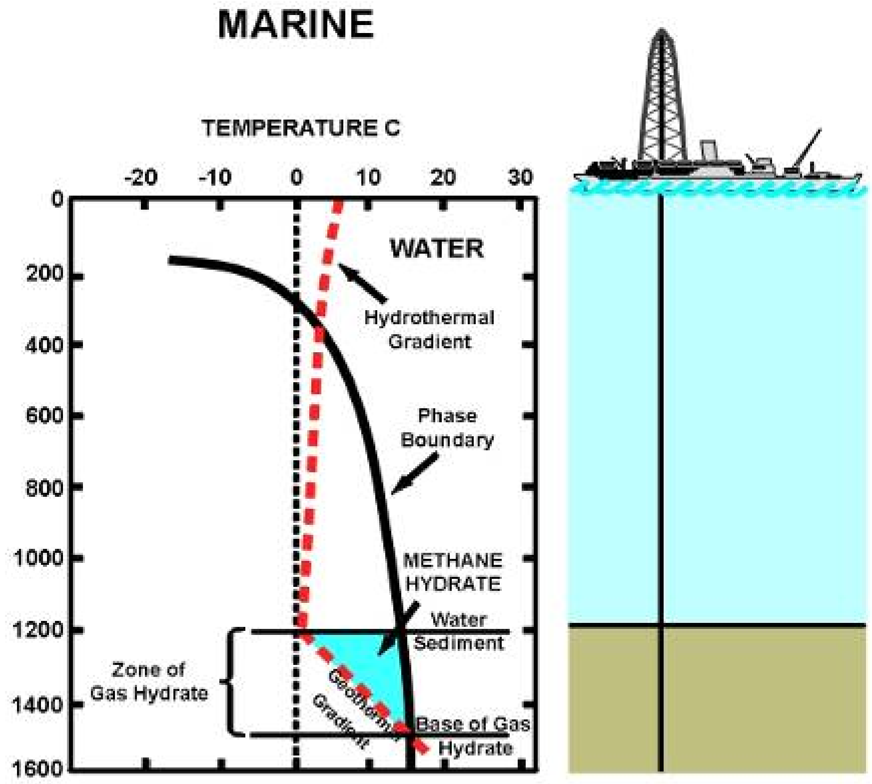
- **Atlantic OCS**

What is Gas Hydrate?

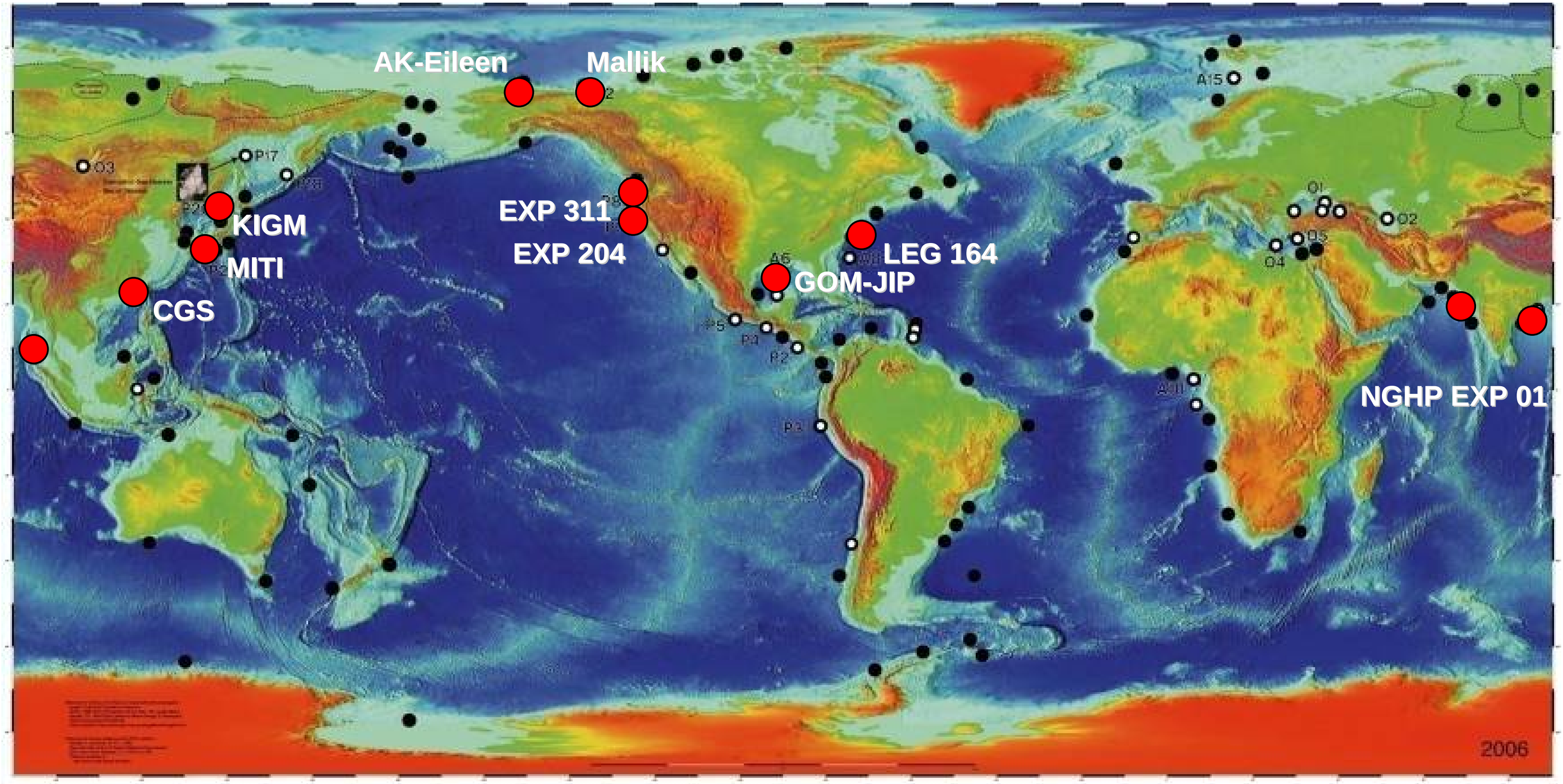
Gas hydrates are ice-like crystalline substances occurring in nature where a solid water lattice accommodates gas molecules (primarily methane, the major component of natural gas) in a cage-like structure, known as a clathrate.



- Gas Hydrates are stable only in high pressure - low temperature environments
- P/T conditions are favorable on OCS where water depth > 350 meters
- Hydrate Stability Zone thickness increases as water depth increases (HSZ exceeds 1,000 m thick in GOM)



Global Gas Hydrate Occurrences



From Tim Collett, USGS Thomas D. Lorenson and Keith A. Kvenvolden

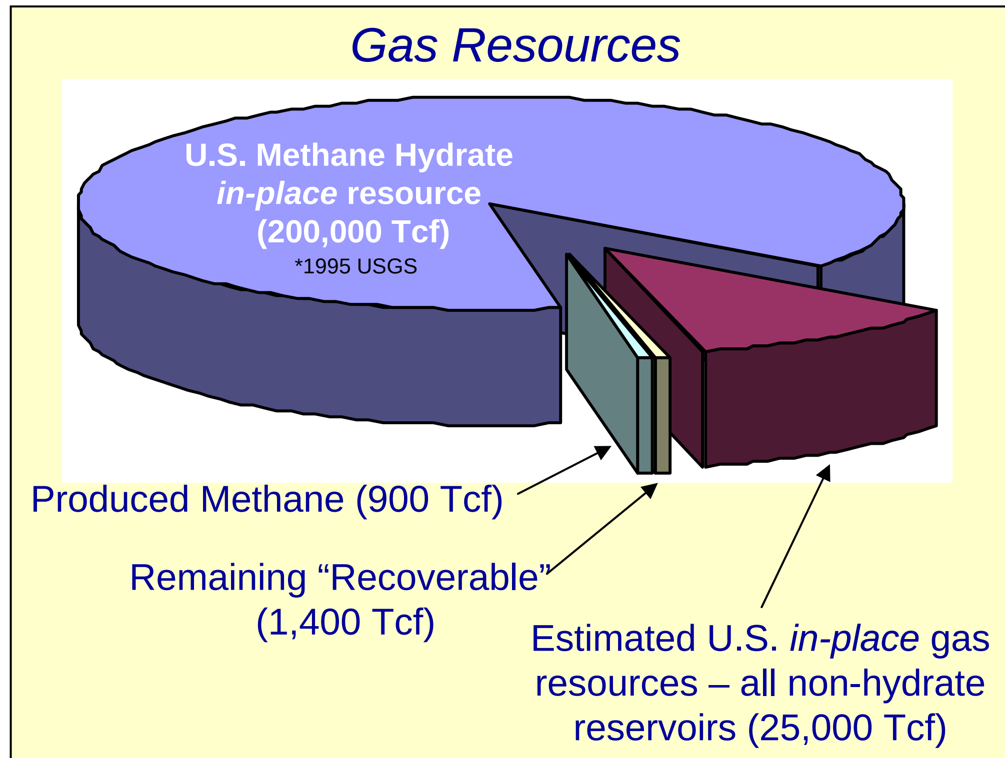
- Recent targeted gas hydrate exploration
- Gas hydrate recovered
- Gas hydrate inferred from other data

MMS *Gas Hydrate Resource Evaluation*

Why are we interested in Gas Hydrate?

Gas hydrate dissociates into methane and water as temperature increases or pressure decreases.

- **Recoverable energy resource !!!**



Massive Gas Hydrate on the Seafloor

- **Very well documented**
- **GOM**
- **Not likely a "resource"**

Photo from NOAA/Ocean Exploration

Gas Hydrate in Sandstones

- **Moderately documented**
- **ANS, Nankai Trough, India**
- **Future energy resource**

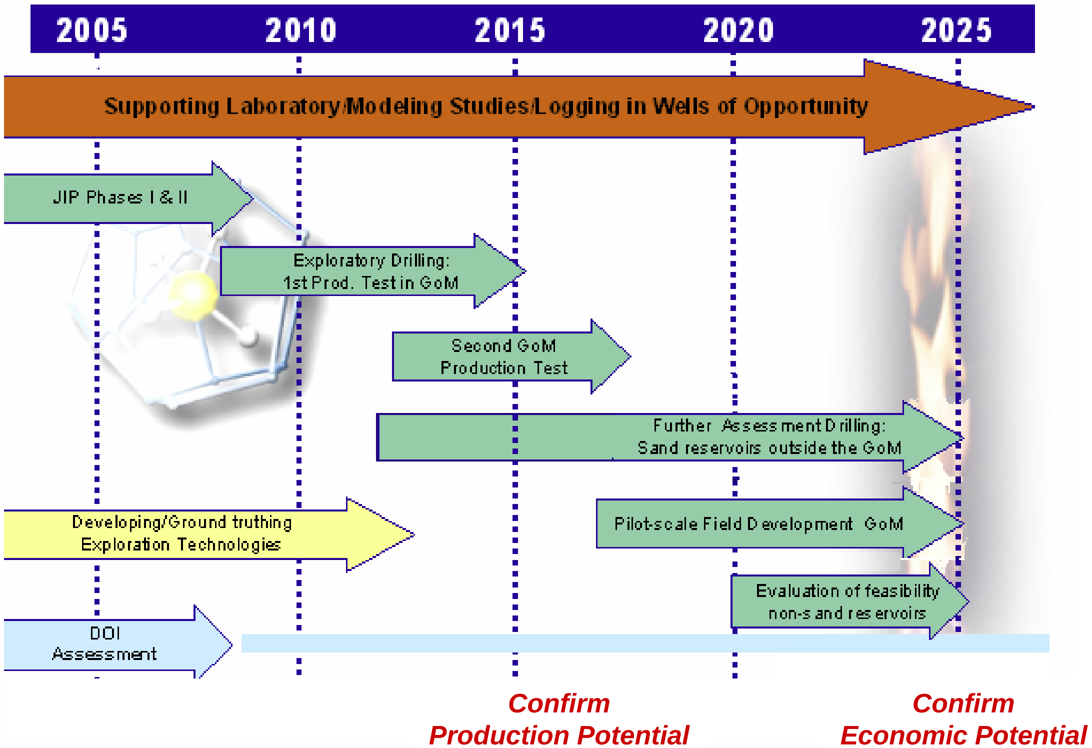
Mt. Elbert #1 core – fine grain sand
Photo from DOE / NETL

➢ Methane Hydrate Research and Development Act of 2000

→ Interagency Coordination Committee (ICC)
→ Technical Coordination Team (TCT)

➢ Energy Policy Act of 2005 (Sec. 968)

R&D roadmap leading to confirmation of economic potential of gas production from marine hydrate

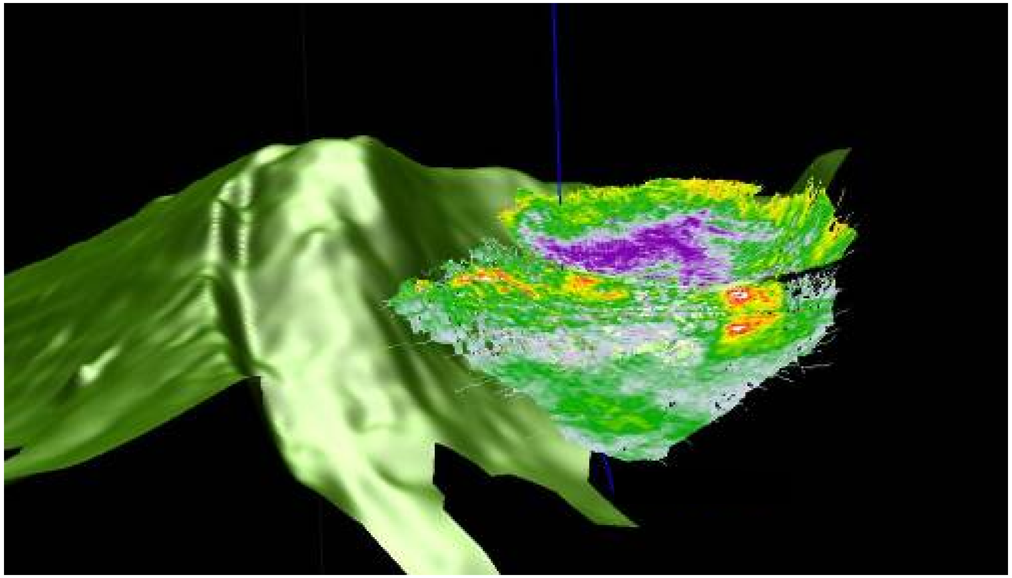


From Dept. of Energy (2006)

The 2005 Act, as reauthorized, directs these seven federal agencies to collaborate on a program to:

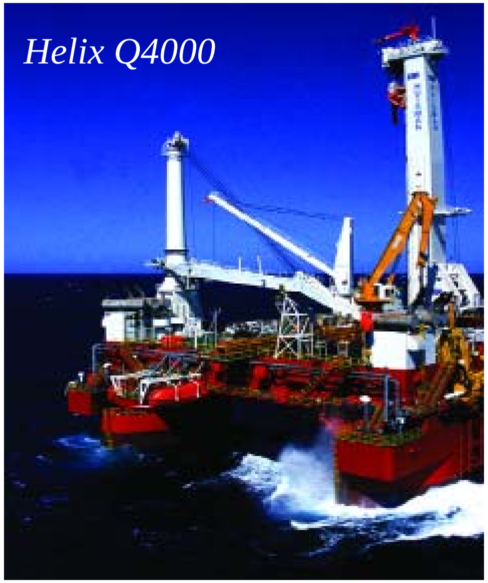
- Conduct basic and applied research to identify, explore, assess, and develop methane hydrate as a source of energy;
- Develop technologies for efficient and environmentally sound development of methane hydrate resources;
- Develop technologies to reduce the risks of drilling through methane hydrate, and identify methane hydrate resources through remote sensing;
- Acquire and reprocess seismic data suitable for characterizing methane hydrate accumulations;
- Conduct exploratory drilling and production testing operations on permafrost and non-permafrost gas hydrates, including drilling of one or more full-scale production test wells;
- Conduct basic and applied R&D to assess and mitigate the environmental impacts of hydrate degassing (both natural and that associated with development);
- Promote education and training in methane hydrate science through dedicated fellowships or other means.

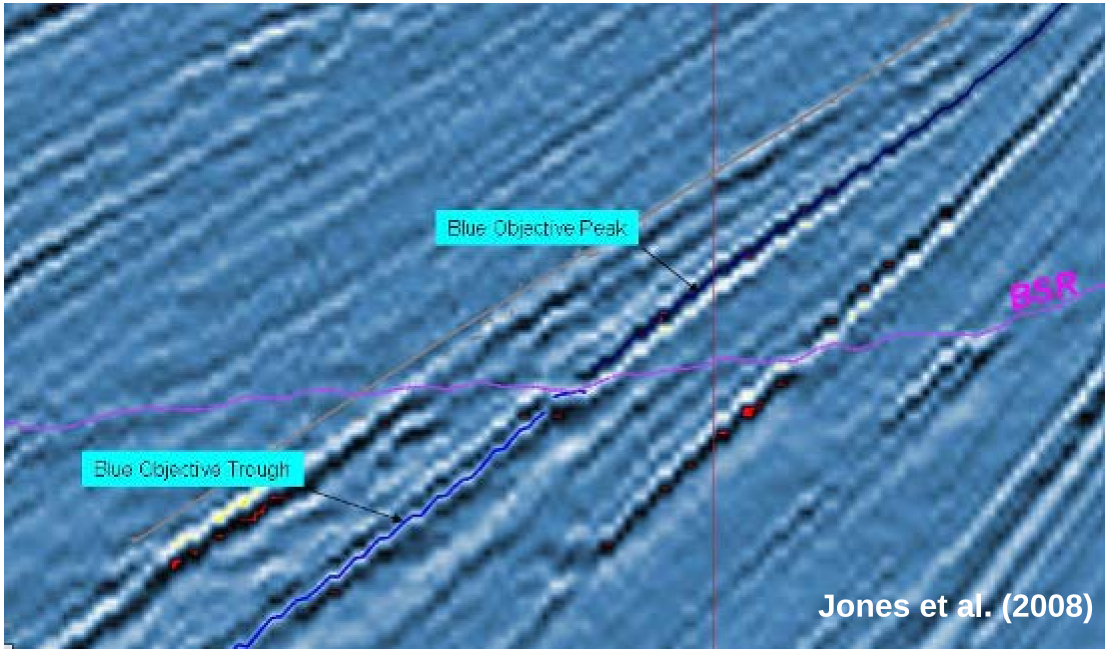
Subsurface Gas Hydrate – How Do We Find It?



Joint Industry Project (JIP)

- DOE funded – Chevron operated; also Conoco, Statoil, etc.
- Confirm exploration technologies for GH in sandy reservoirs
- LWD leg planned for Spring 2009
- Mature sites identified in Green Canyon and Walker Ridge





MMS Gas Hydrate Resource Evaluation

Gas Hydrate Assessment
U.S. Gulf of Mexico

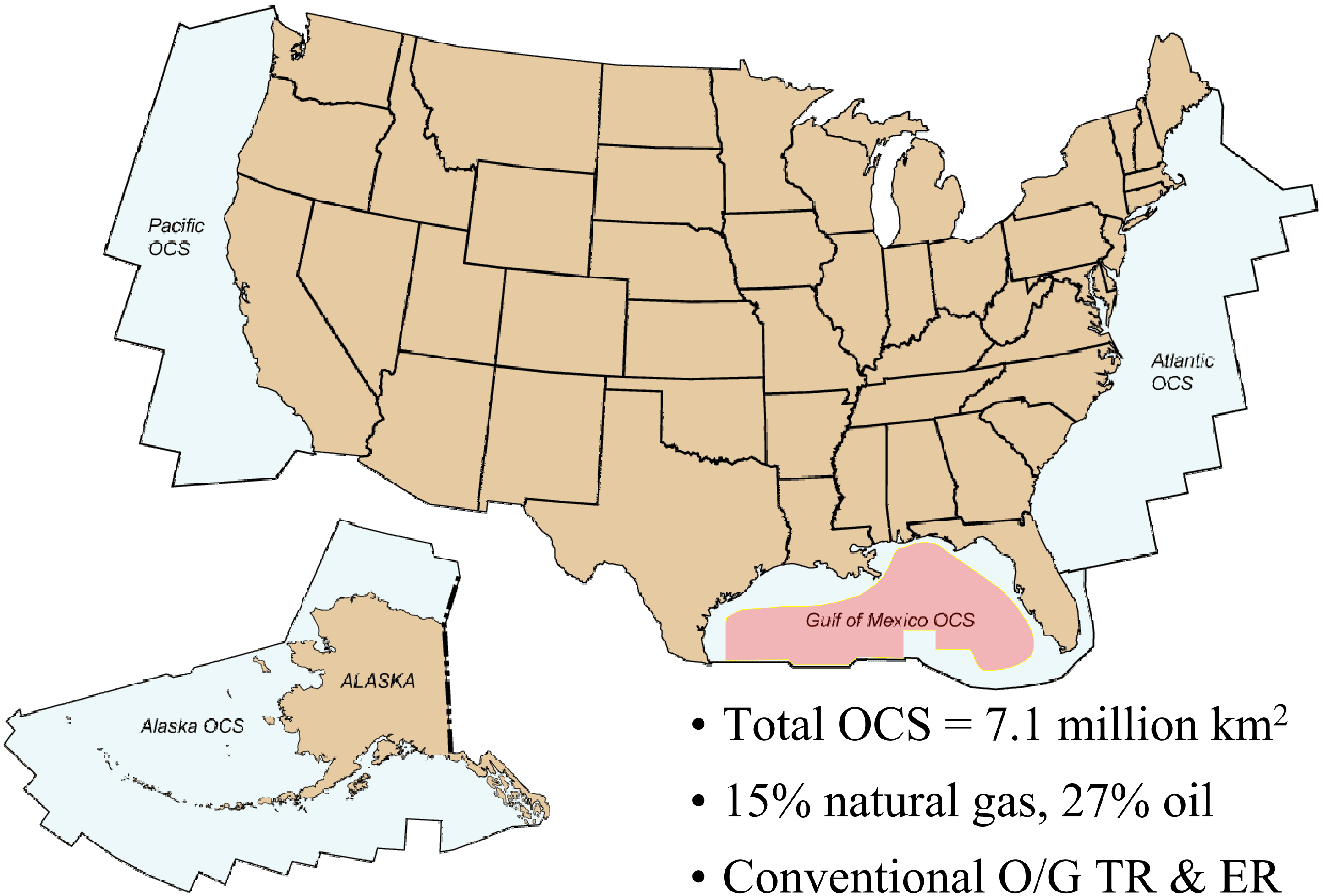
Matt Frye
Jesse Hunt
Bill Shedd

John Grace
Gordon Kaufman
John Schuenemeyer

Tim Collett
Rick Colwell
Richard Desselles
Barry Dickerson
Scott Edwards

Ray Faith
Dick Fillon
Jeff Hanor
Gary Lore
Charlie Paull

Pulak Ray
Carolyn Ruppel
Roger Sassen
Dendy Sloan

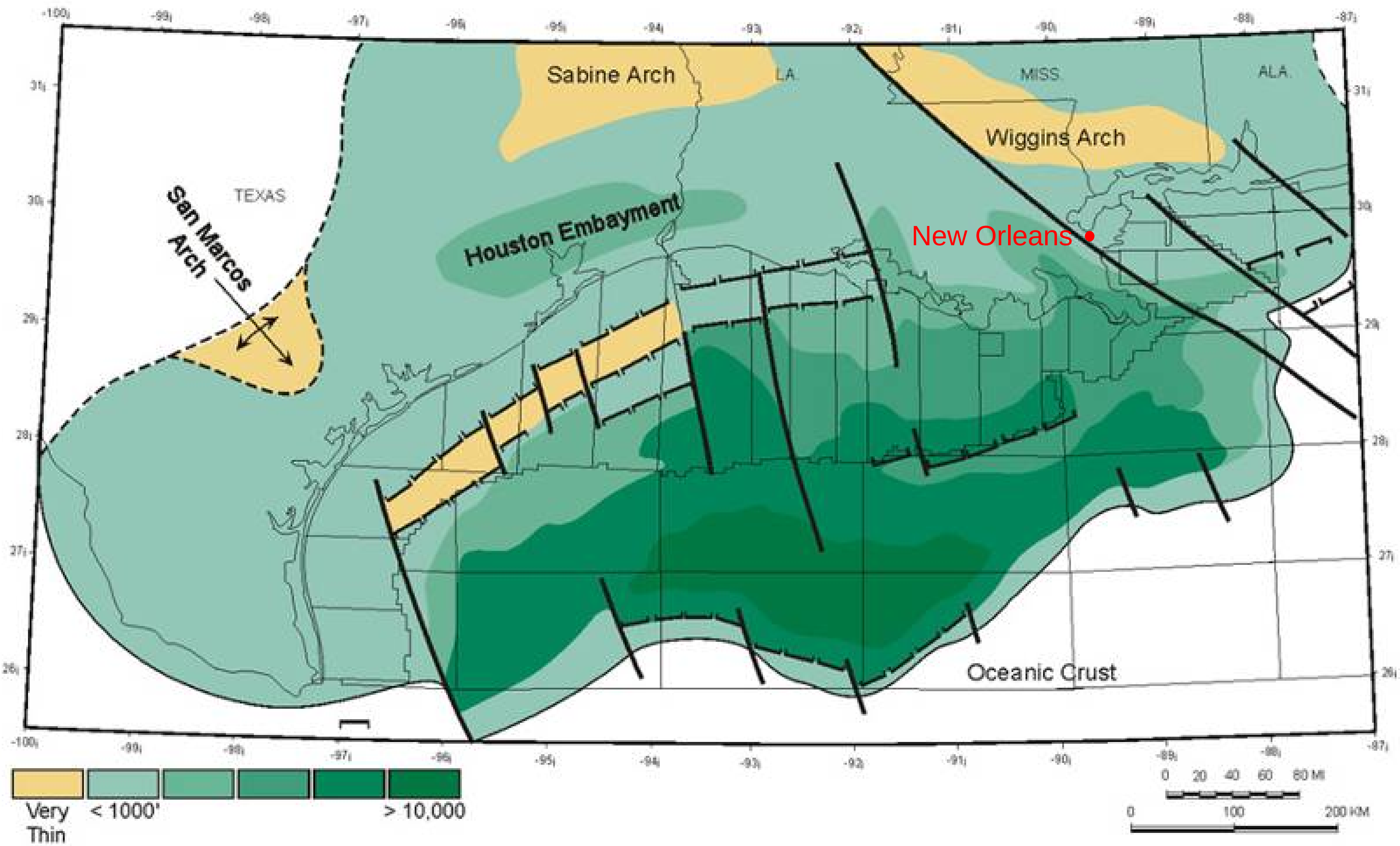


- Total OCS = 7.1 million km^2
- 15% natural gas, 27% oil
- Conventional O/G TR & ER
- Goal: same for Gas Hydrate

Regional Geology – GOM

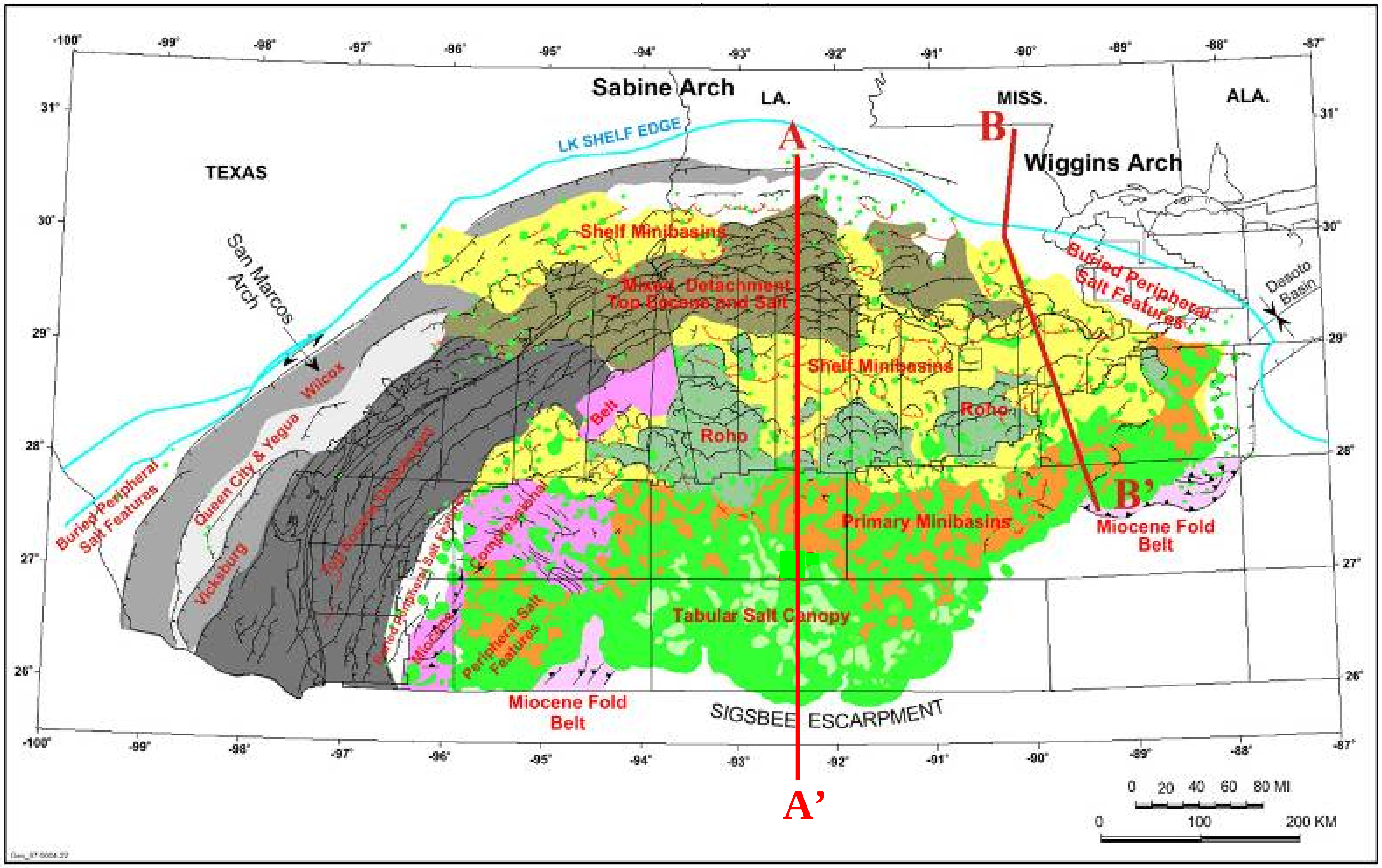
Gulf of Mexico Original Salt Distribution

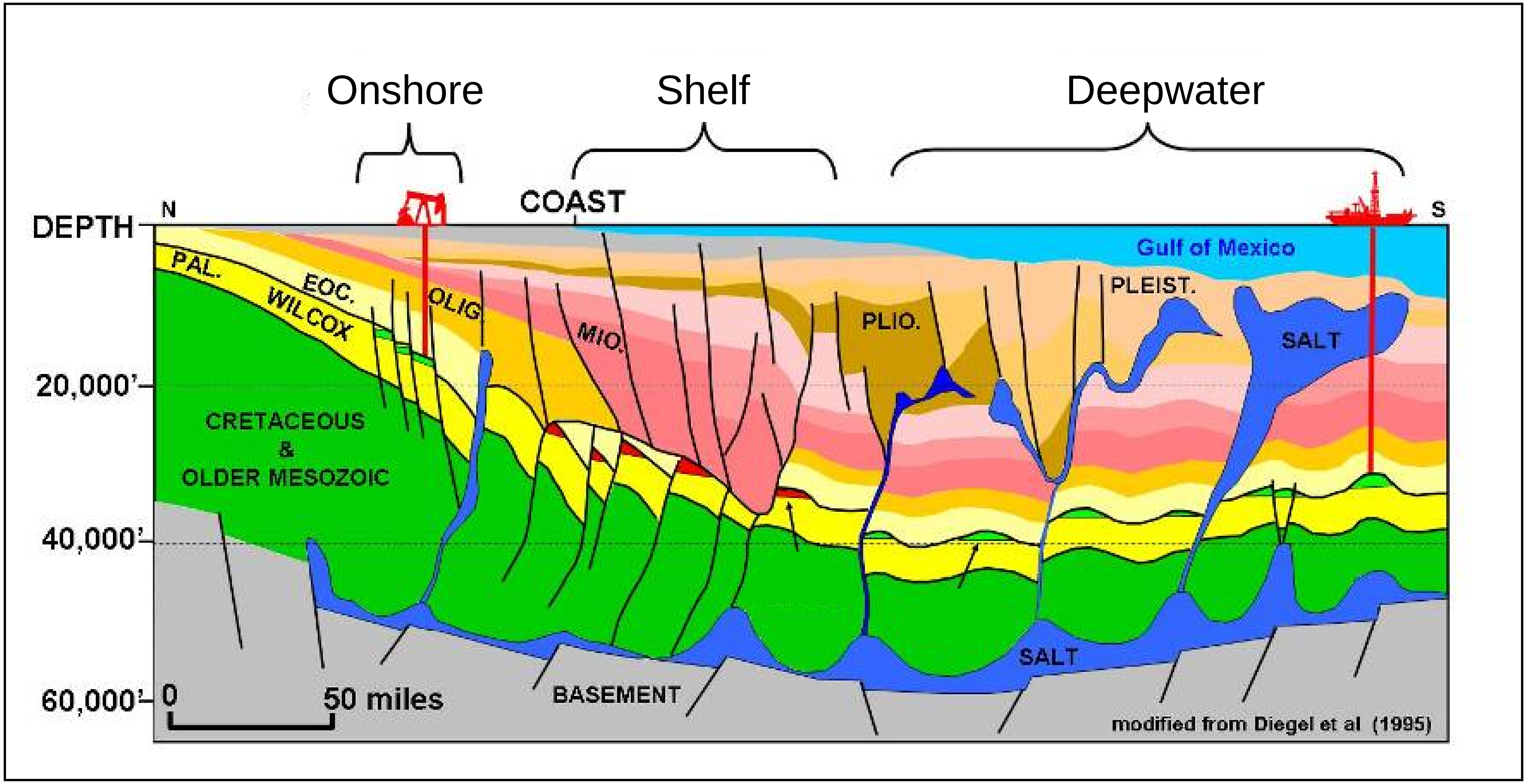
Karlo & Shoup (1986)

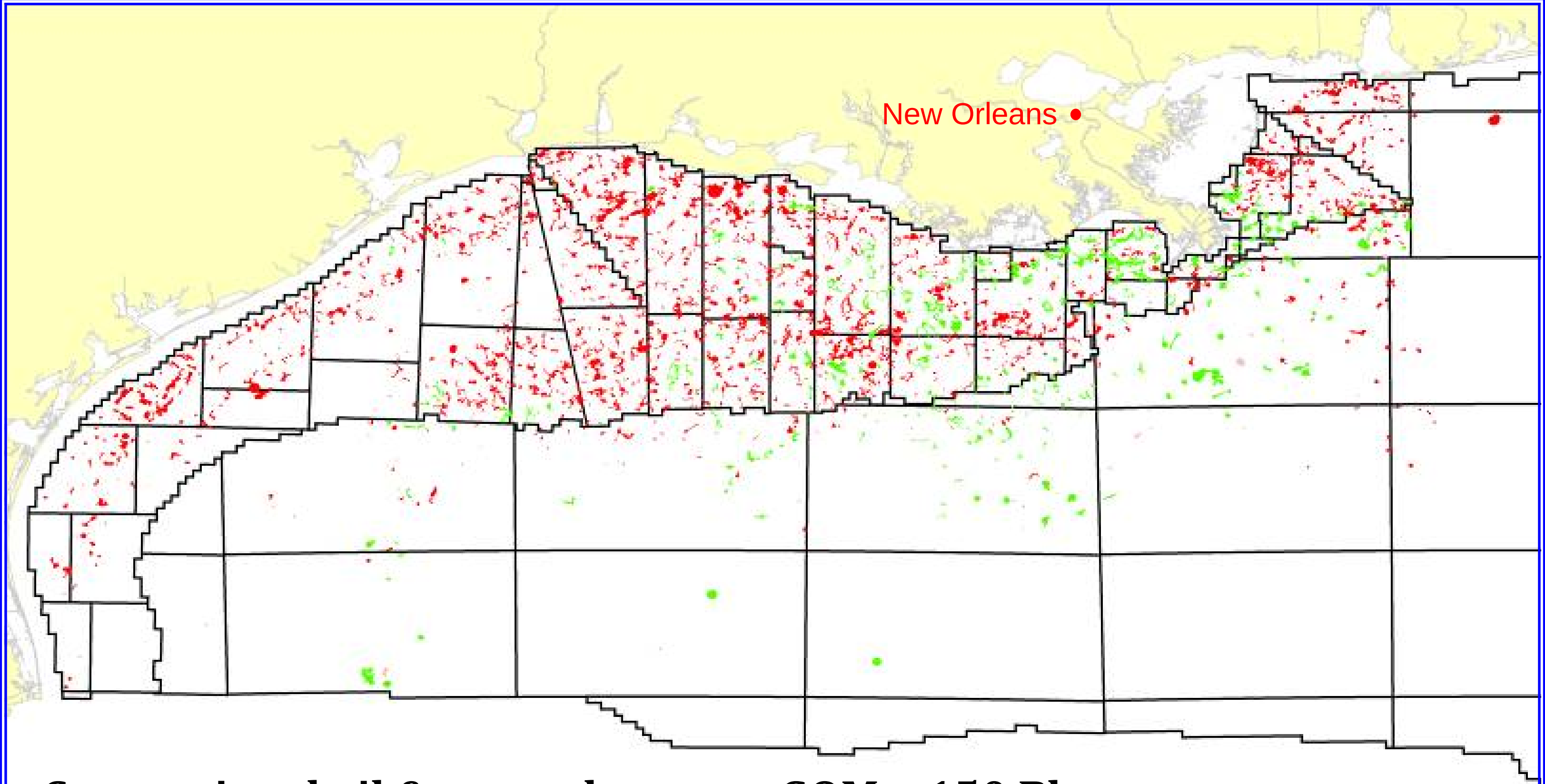


Gulf of Mexico Structural Provinces

Karlo & Shoup (1986)

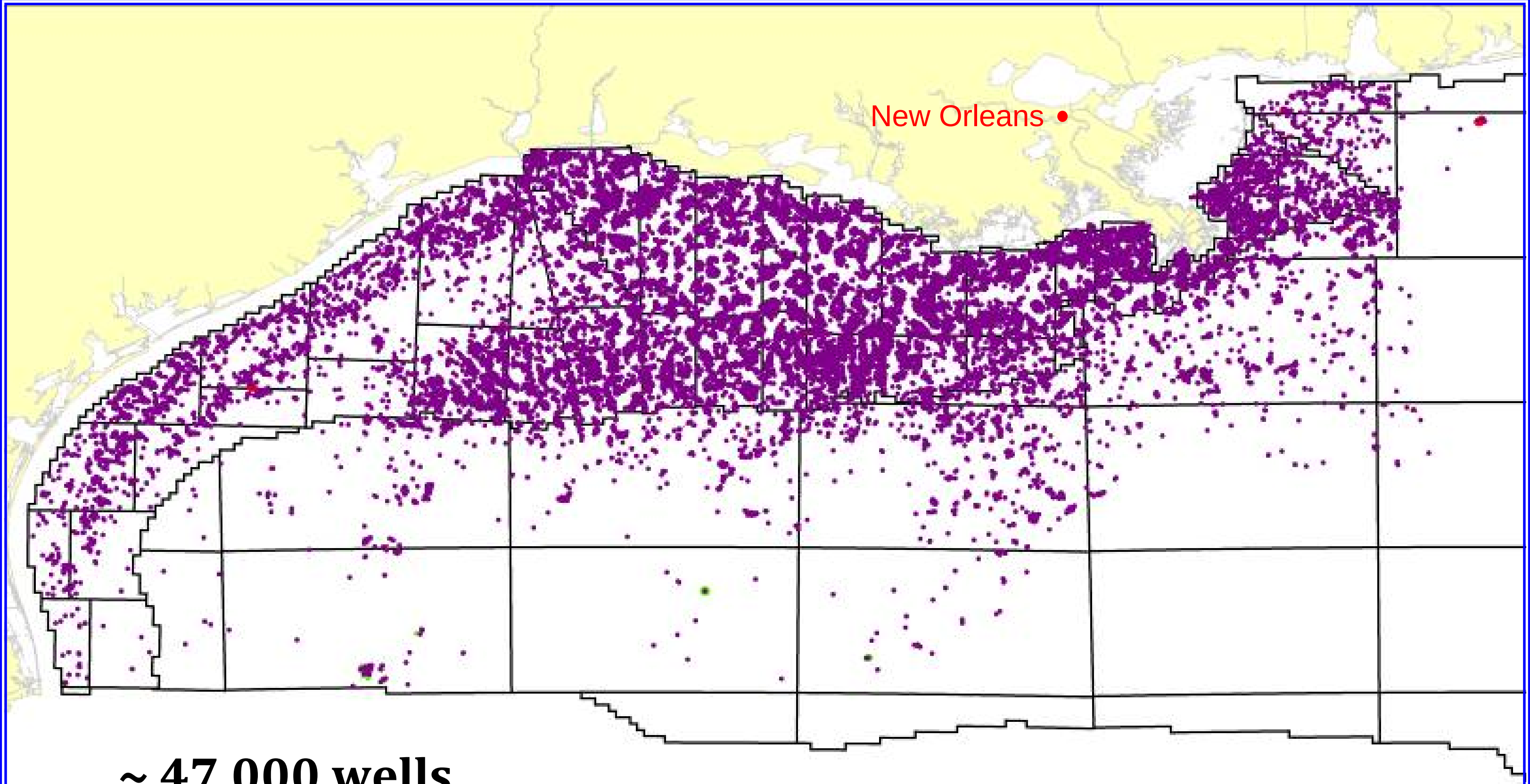



Onshore
Shelf
Deepwater
COAST
DEPTH
N
S
Gulf of Mexico
PAL.
EOC.
WILCOX
OLIG.
MIO.
PLIO.
PLEIST.
SALT
20,000'
CRETACEOUS
&
OLDER MESOZOIC
40,000'
SALT
60,000'
0
50 miles
BASEMENT
modified from Diegel et al (1995)



Conventional oil & gas endowment GOM ~ 150 Bboe

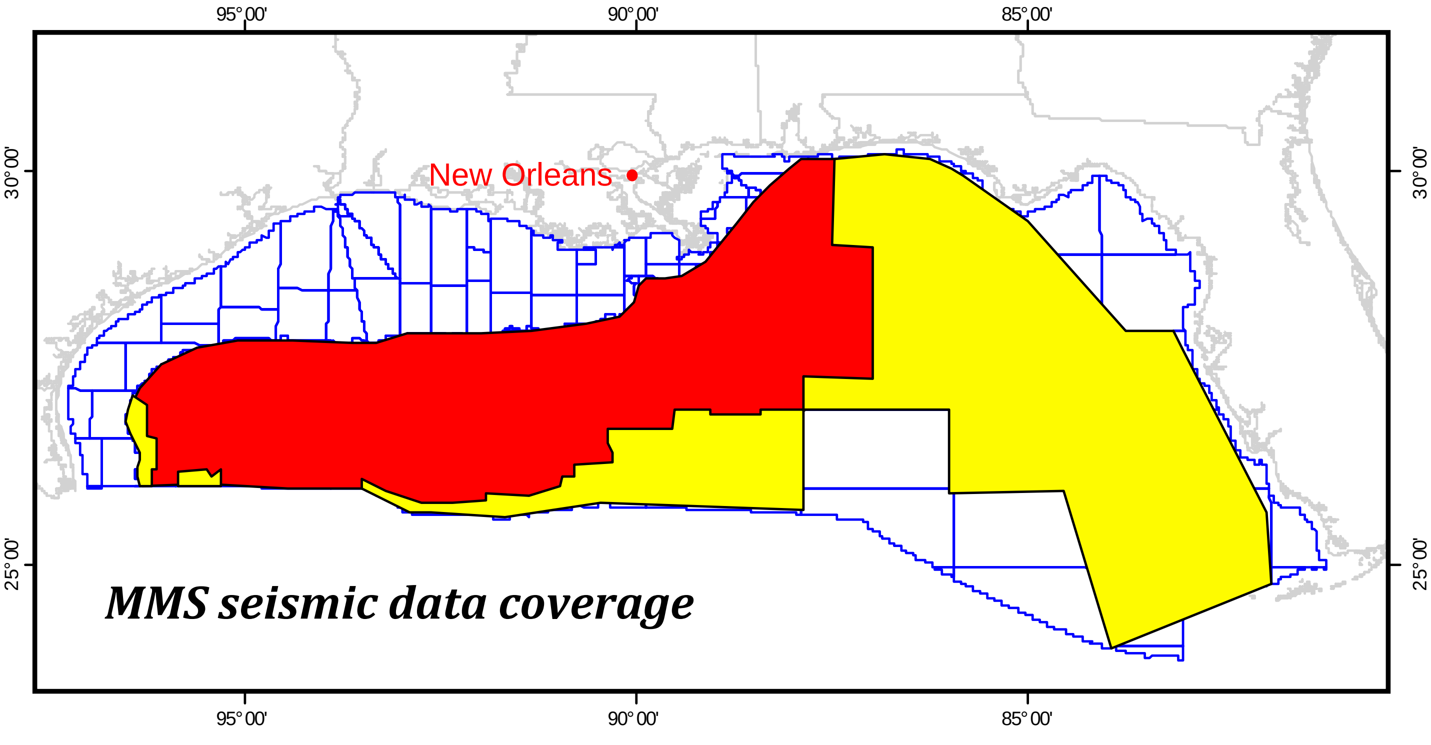
- Cumulative production
- Reserves
- Undiscovered resources



~ 47,000 wells

3-D coverage (~200,000 km²)

2-D coverage (~225,000 km²)



Model Specifications

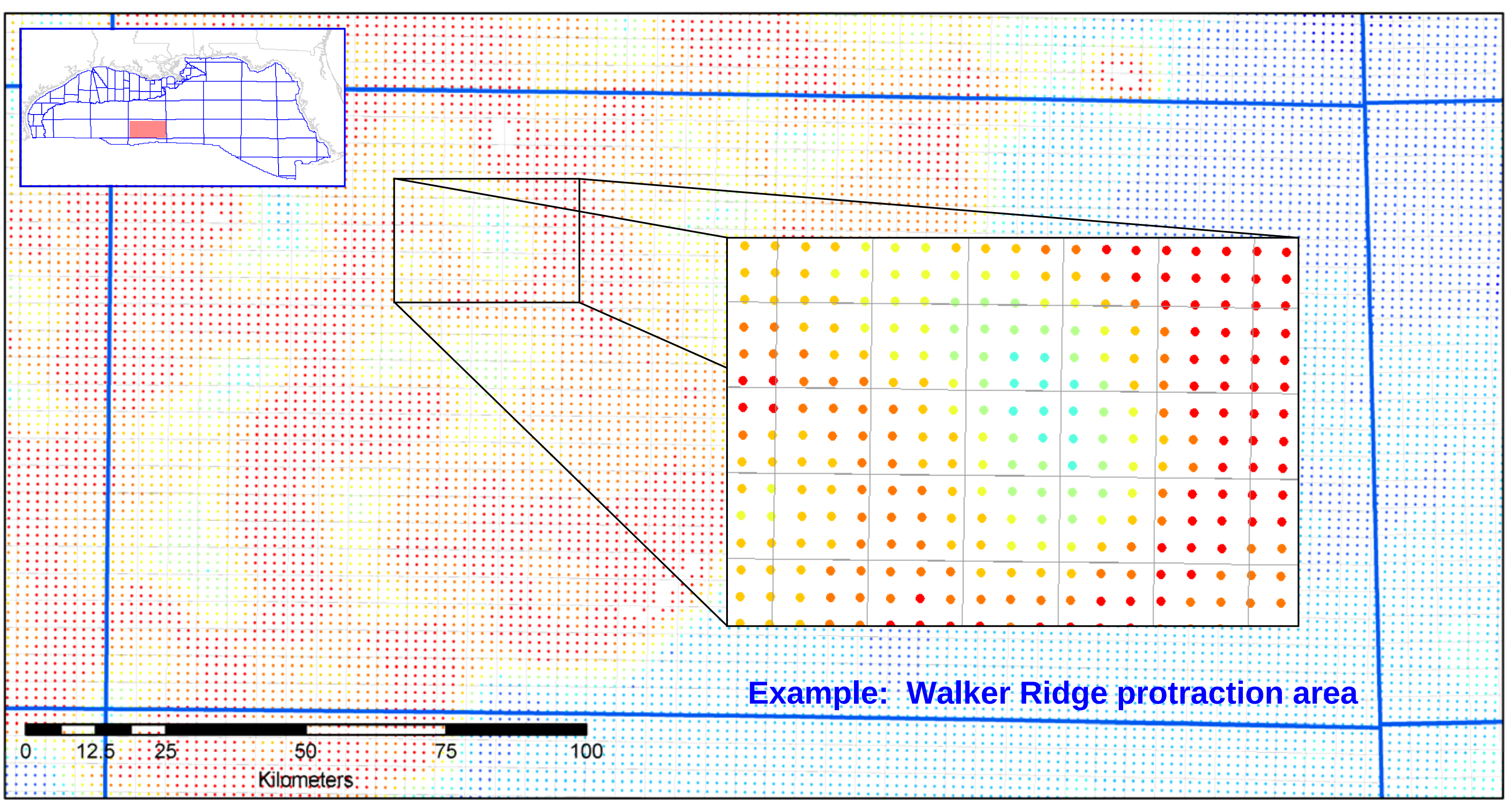
- Study area ~ **450,000 km²**
- **202,079** model cells – each cell **2.32 km²** (5,000' x 5,000')

- **Stochastic** ⟶ 1,000 Monte Carlo trials (capable of 4,000 trials)

- **Mass Balance** allows for extreme variable disaggregation / modification

- Outputs are **GIS-ready** and easily mappable

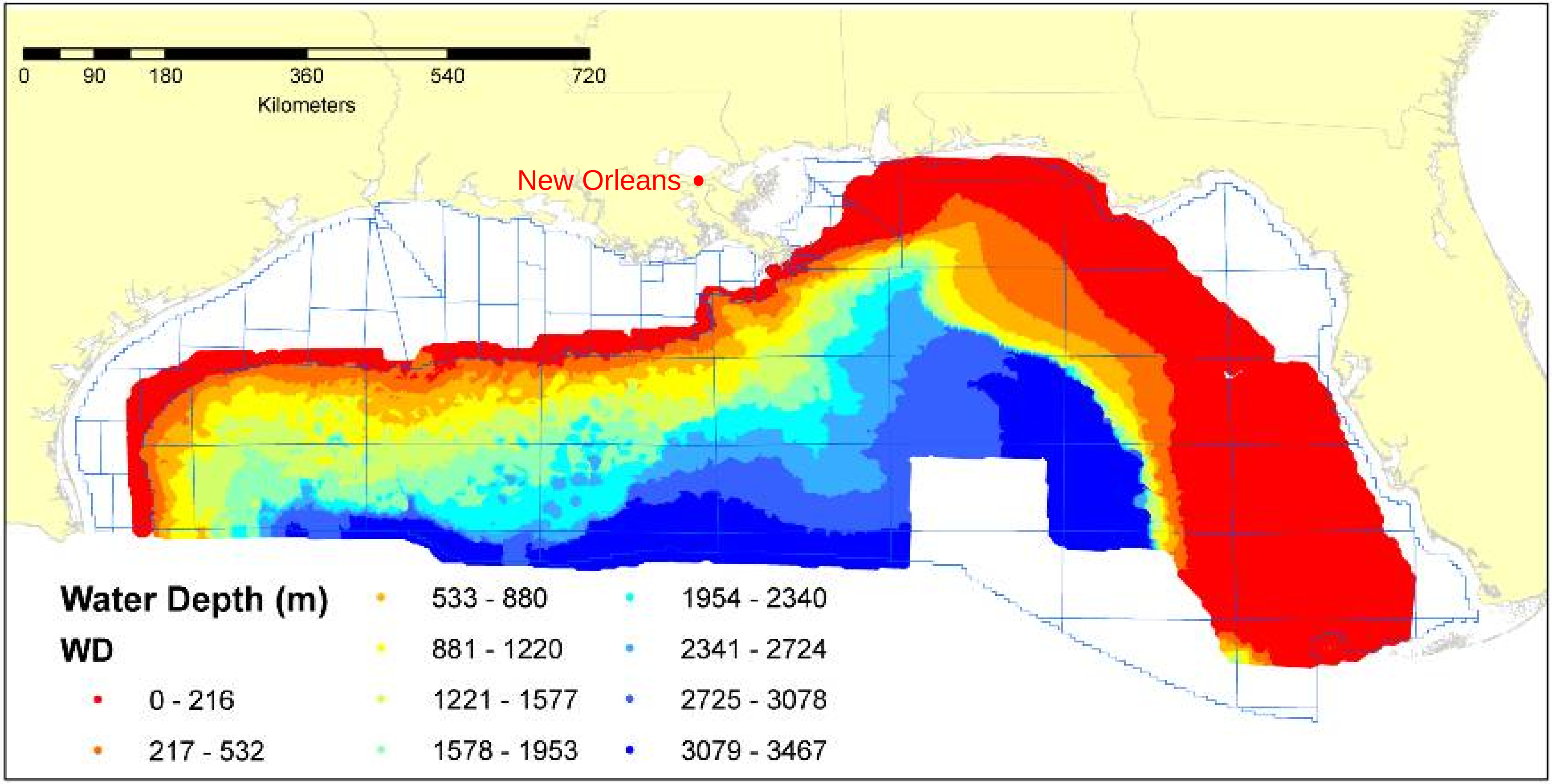
- Programmed in FORTRAN version 90 (Compiled as v. ***GOM3.38***)
- R used for summary statistics and graphics


Example: Walker Ridge protraction area
0
12.5
25
50
75
100
Kilometers

Spatial Input Data

1. Bathymetry
2. Top Salt Structure
3. Vertical Sand Percent
4. Surficial Seismic Anomalies

AreaID	Lat	Lon	SandPerc	WD	Salt	Anomaly	BasinID	Curve	Percconvex	Vertical
cgom	29.30571	-88.65986	24	74	600	0	46	6.42E+08	0.2785004	0
cgom	29.3052	-88.64421	23	78	1425	0	46	1.70E+08	7.38E-02	0
cgom	29.29098	-88.62915	23	78	1656	0	46	2.59E+08	0.1123339	0



ArealD	Lat	Lon	SandPerc	WD	Salt	Anomaly	BasinID	Curve	Percconvex	Vertical
cgom	29.30571	-88.65986	24	74	600	0	46	6.42E+08	0.2785004	0
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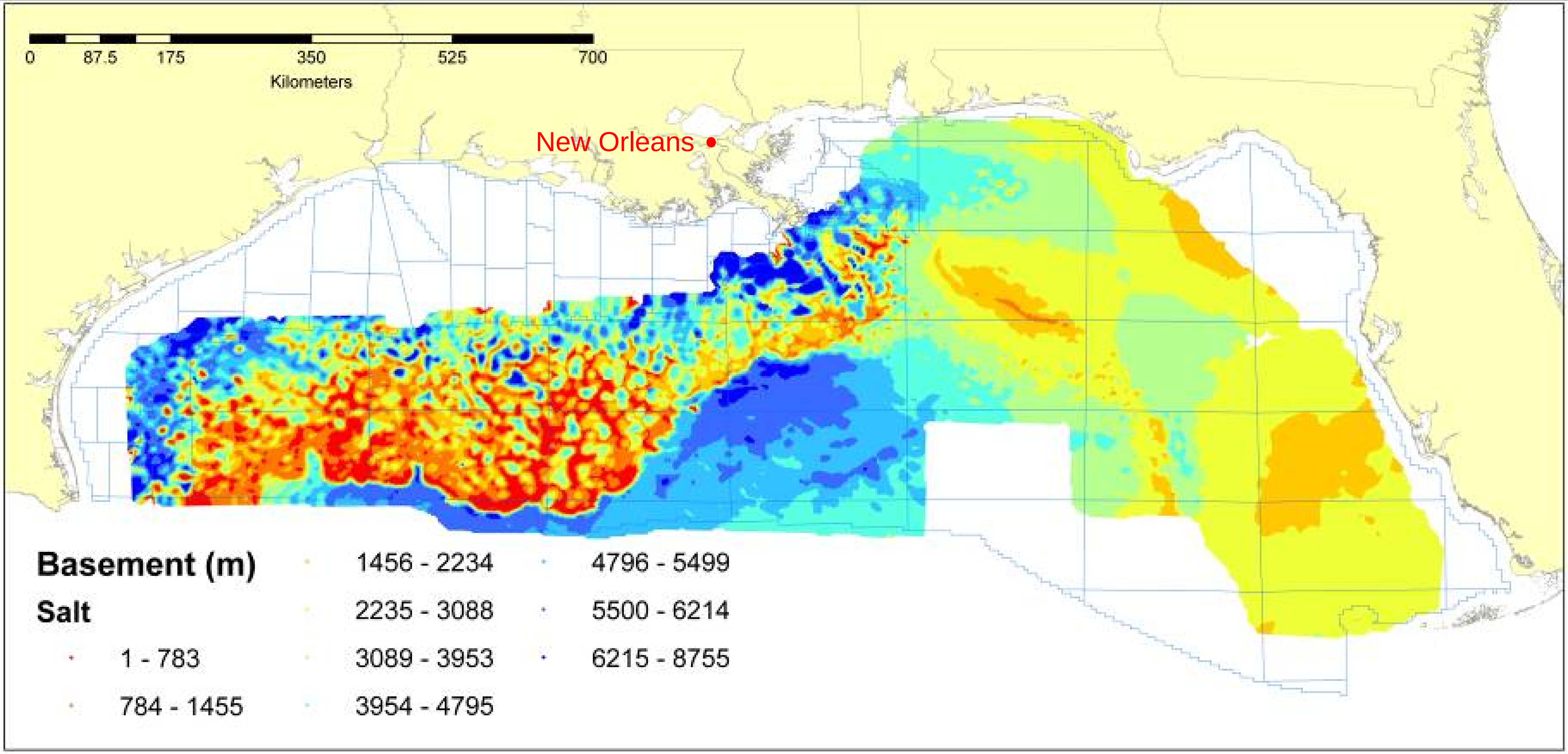

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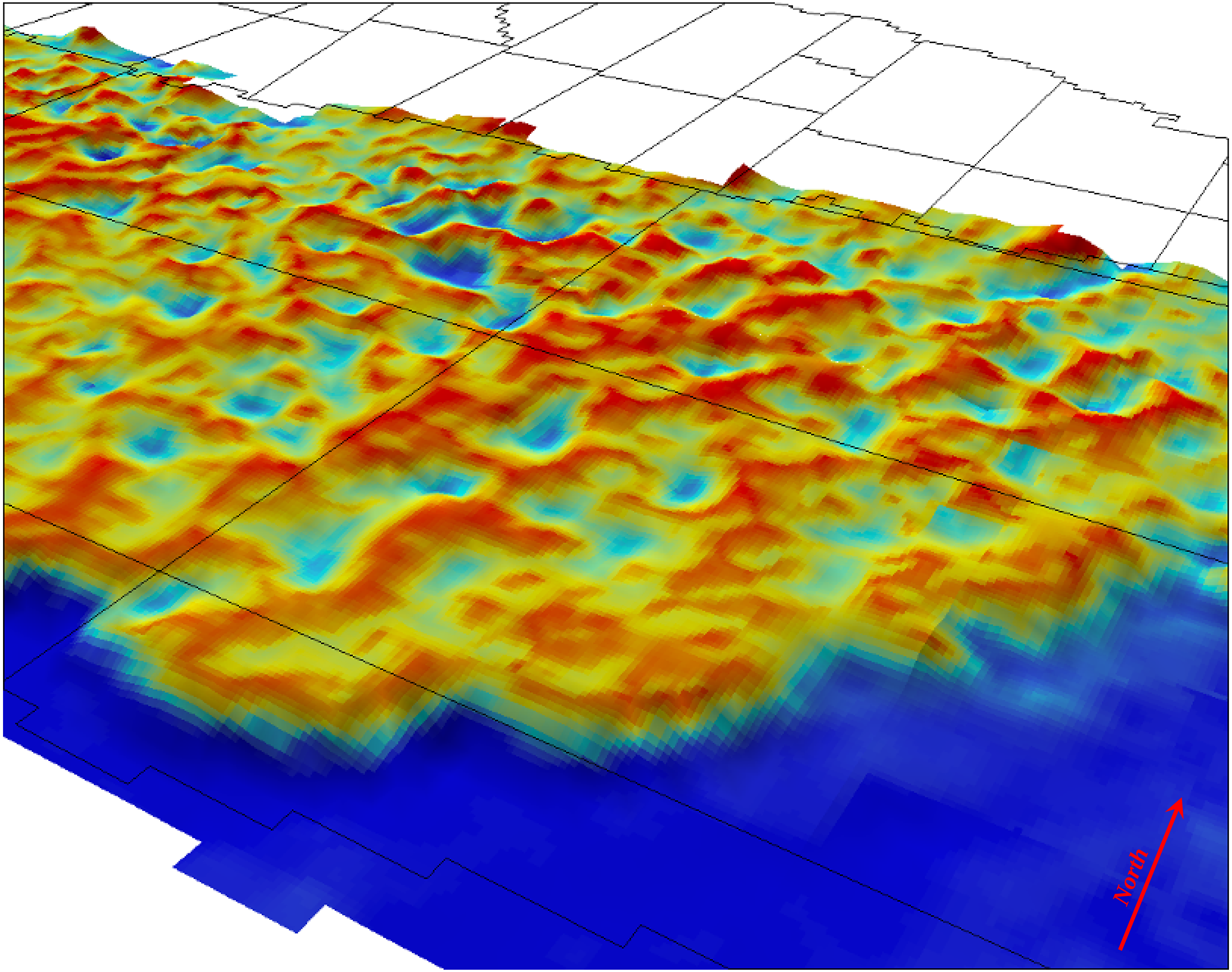
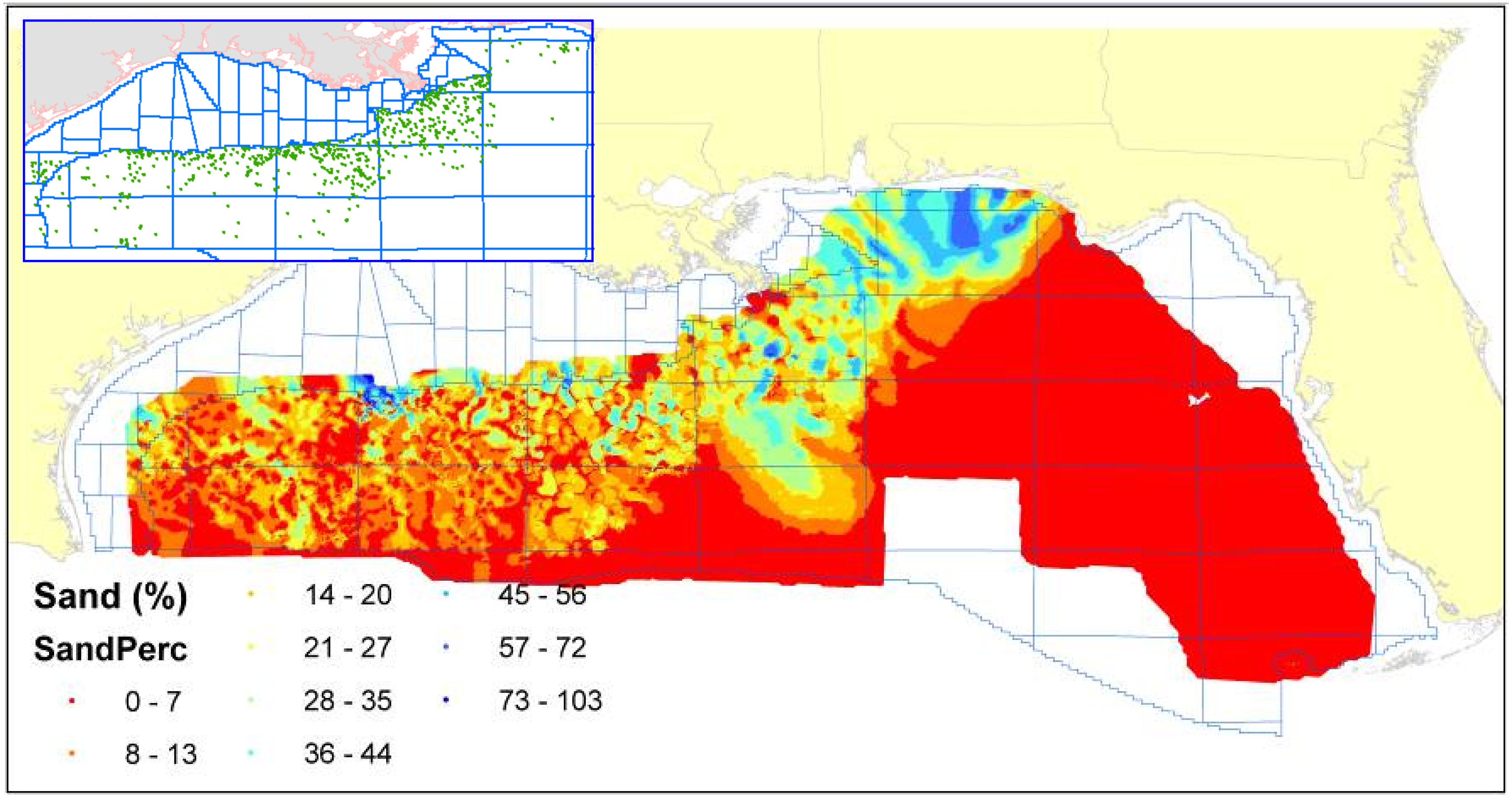

North



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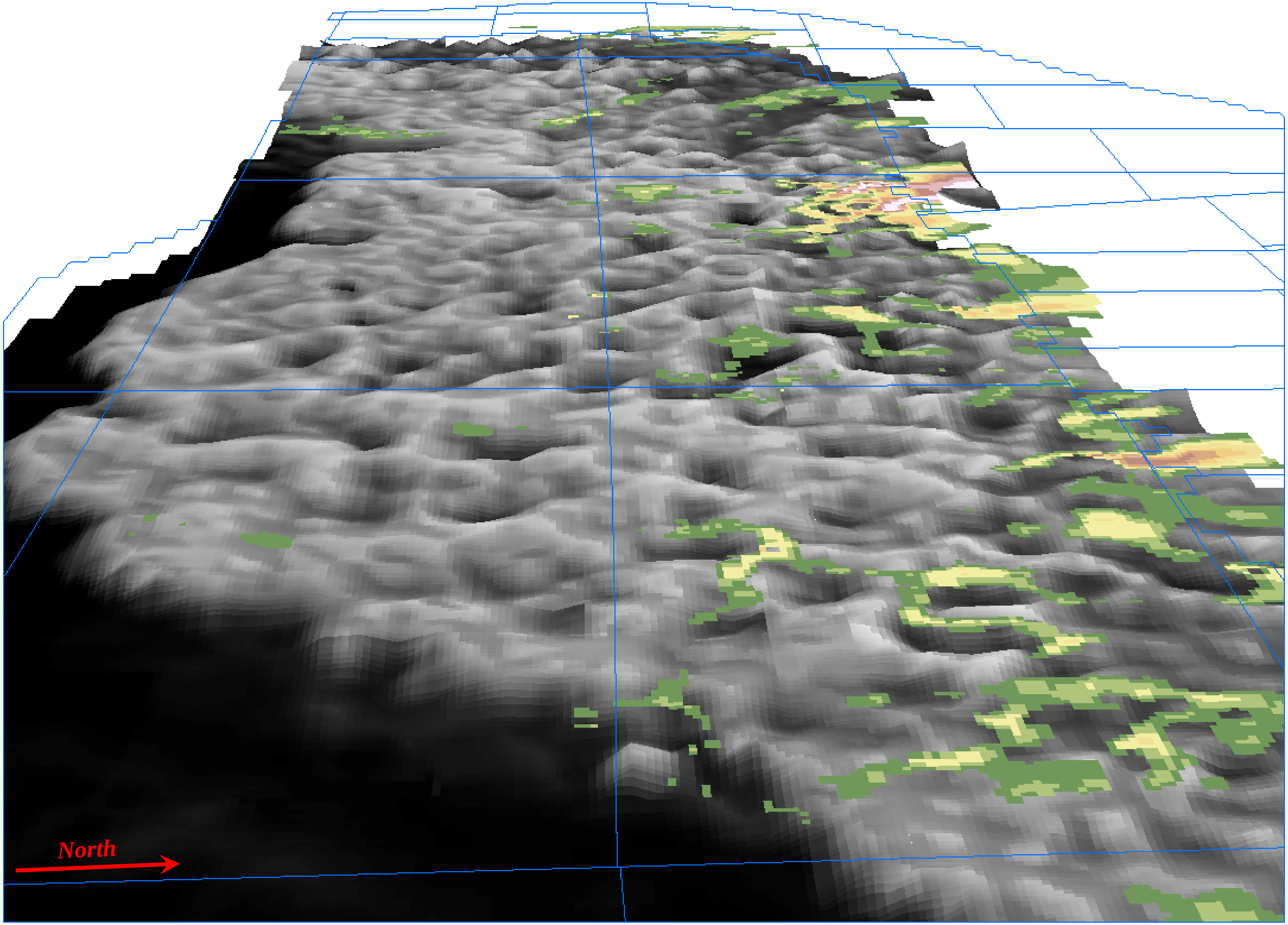
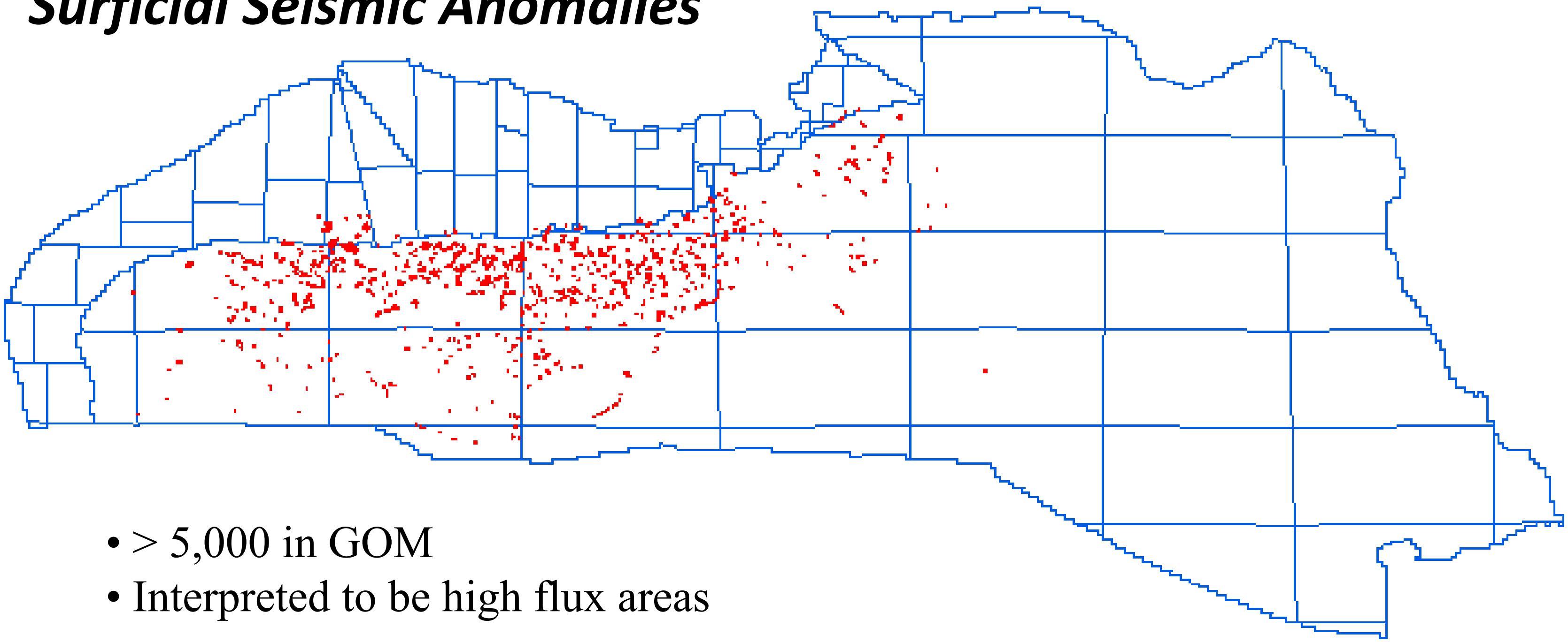

North

Surficial Seismic Anomalies



- > 5,000 in GOM
- Interpreted to be high flux areas

ArealD	Lat	Lon	SandPerc	WD	Salt	Anomaly	BasinID	Curve	Percconvex	Vertical
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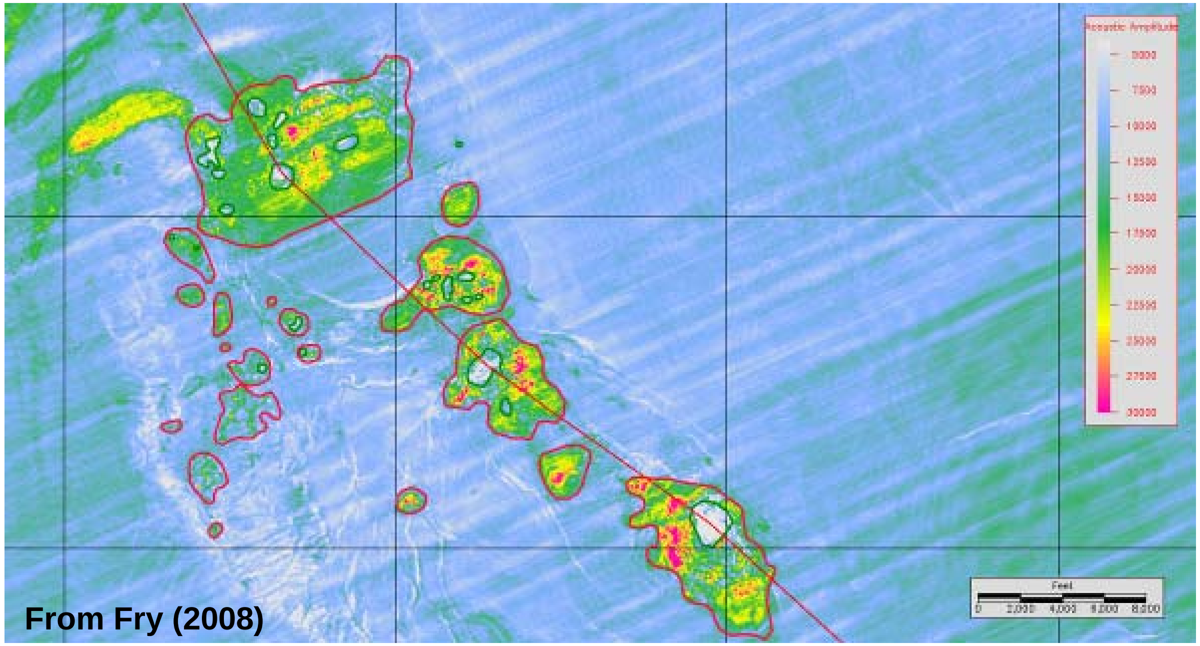
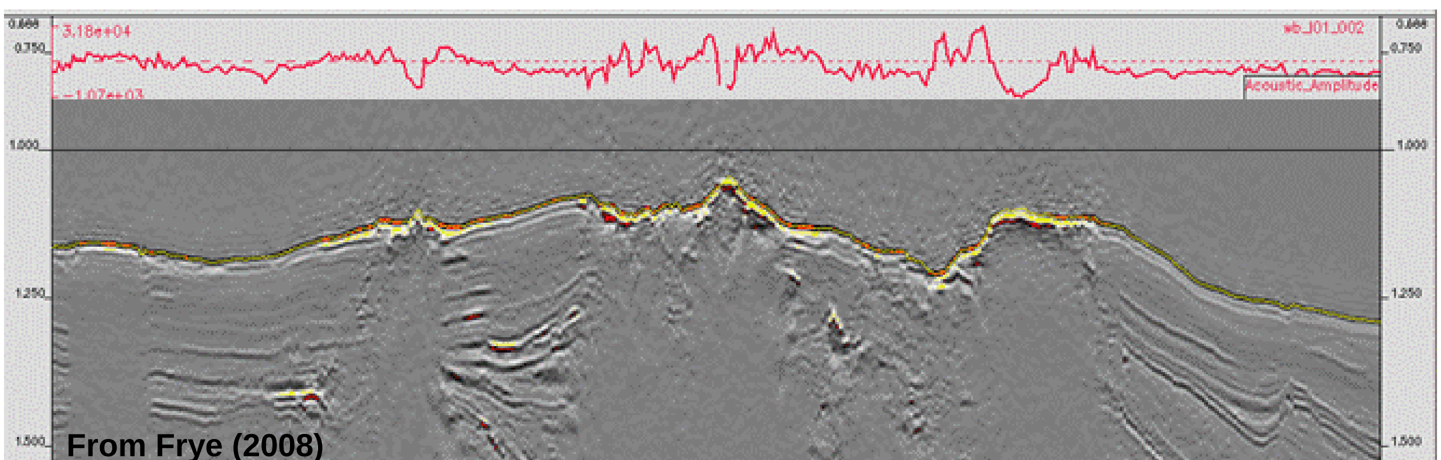
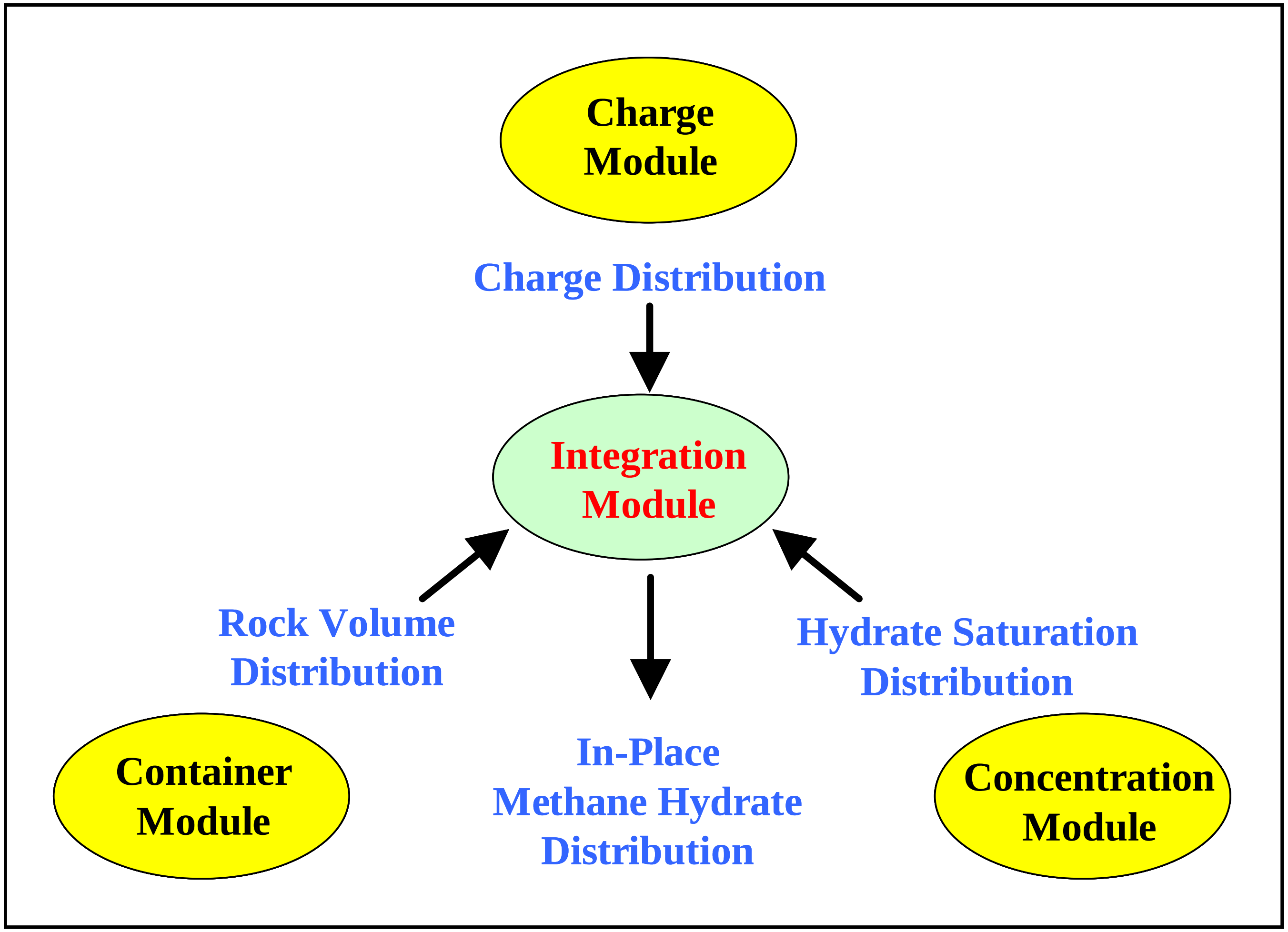


From Fry (2008)



From Frye (2008)

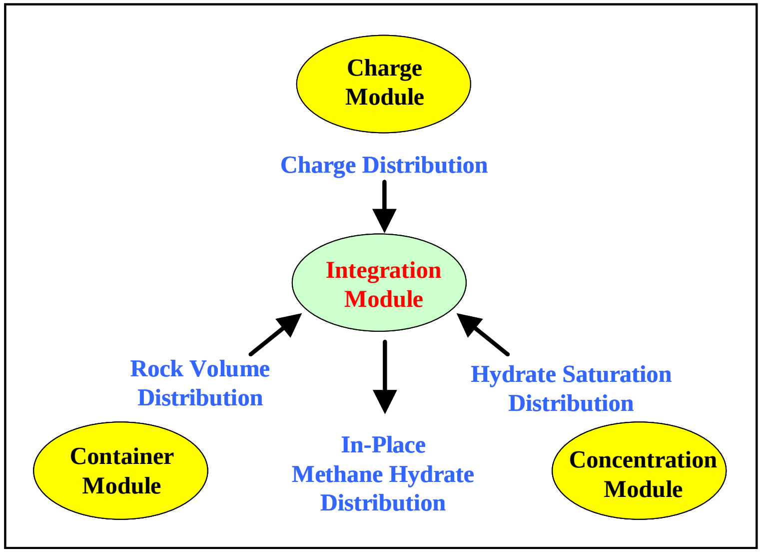
Methodology & Model Structure


Charge
Module
Charge Distribution
Integration
Module
Rock Volume
Distribution
Hydrate Saturation
Distribution
Container
Module
In-Place
Methane Hydrate
Distribution
Concentration
Module

Charge Module

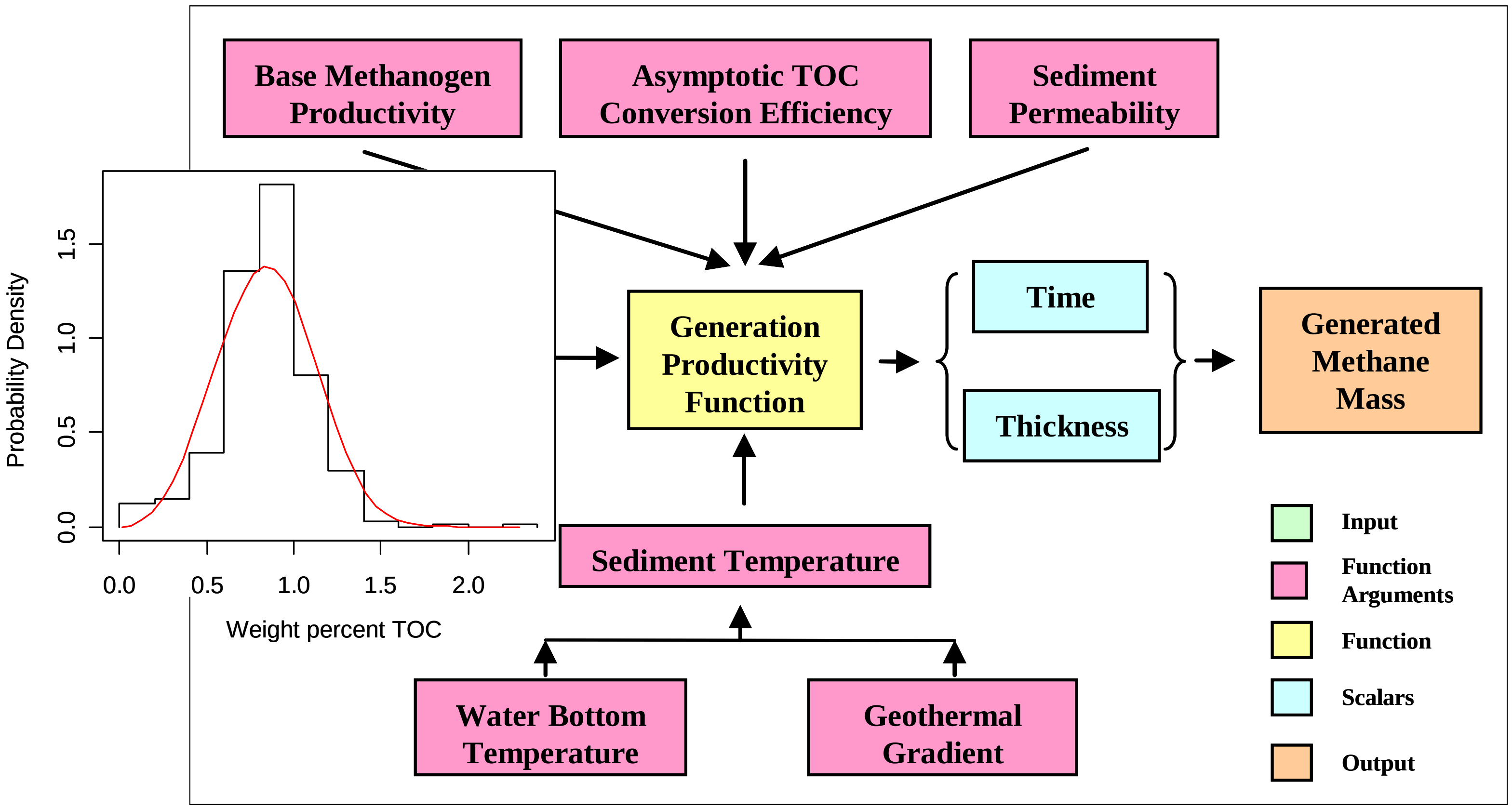
Generation Model

Migration Model

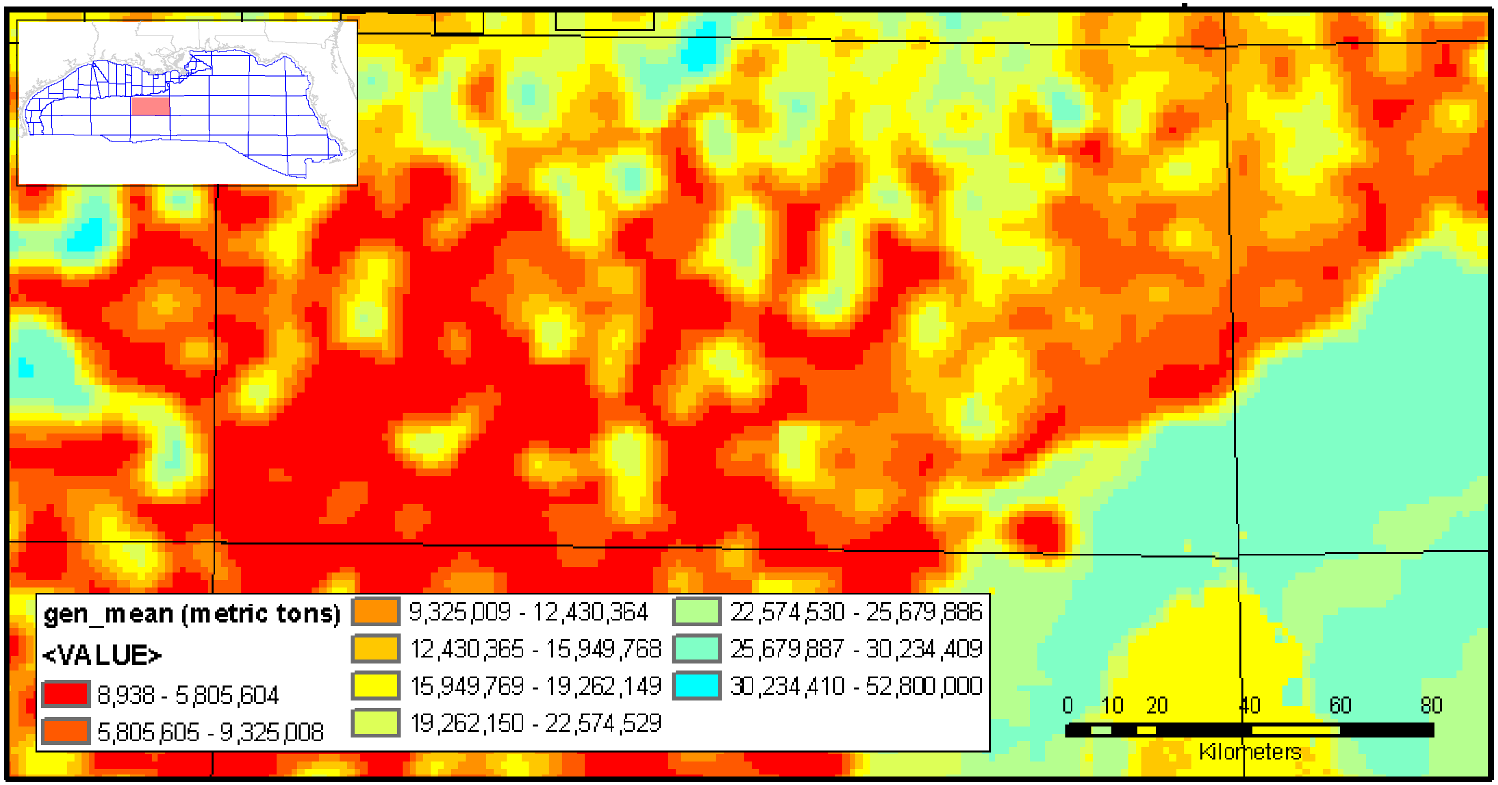


Charge: Generation model

** biogenic gas charge only **



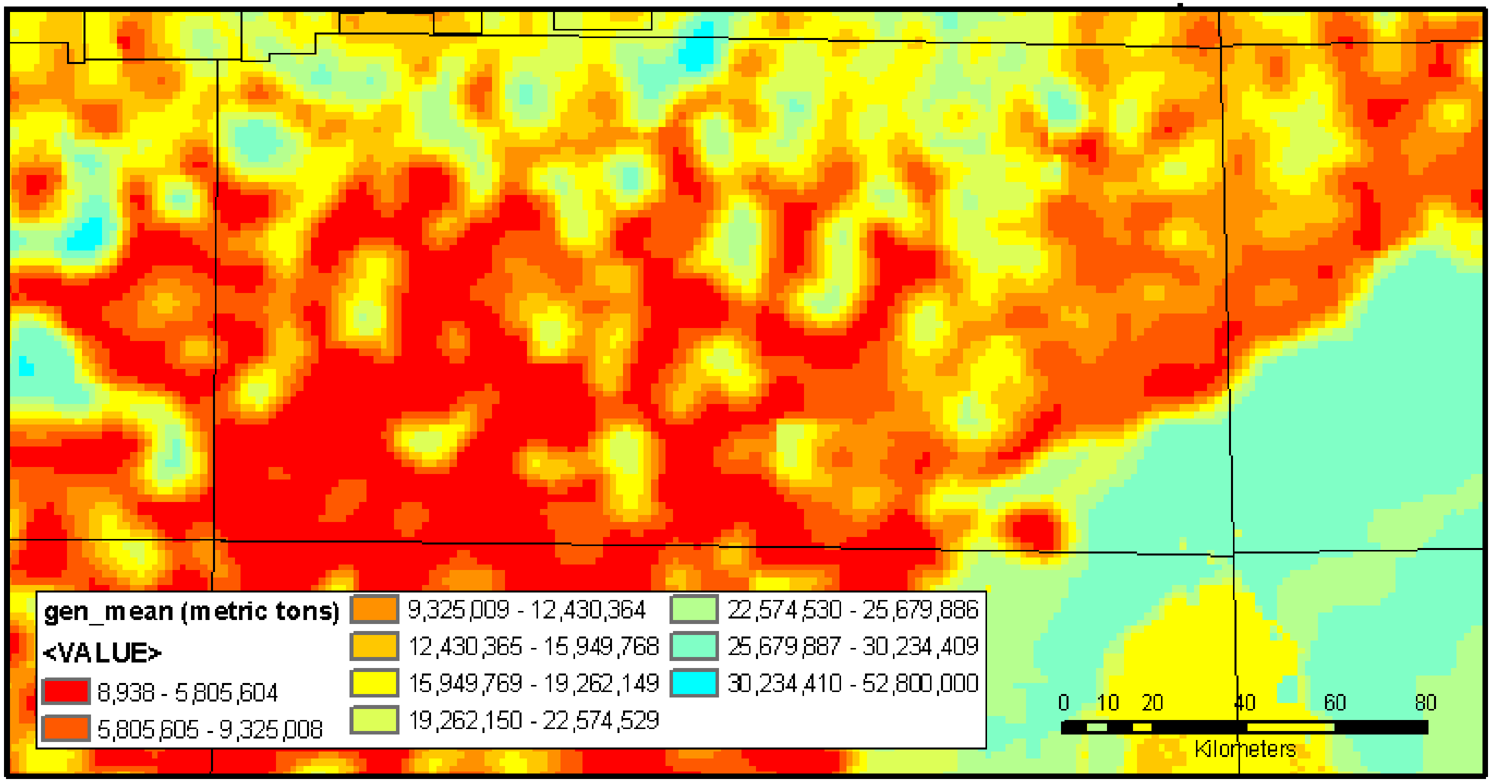
Charge: **Generation model** → Output

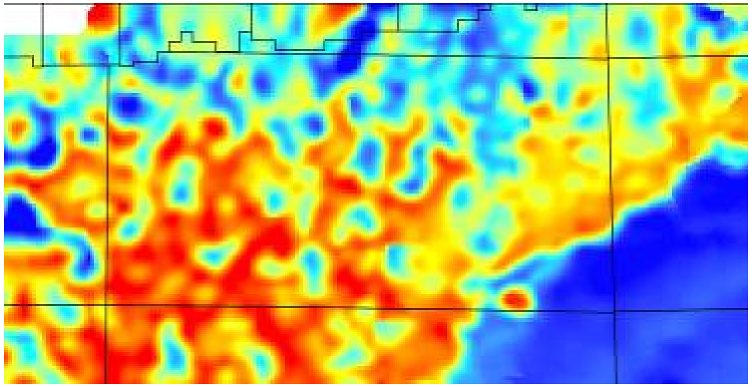


Charge: **Migration model** ⟶ *two end members*

100% vertical and 100% dip-driven

At 100% vertical, all gas generated in a model cell remains in that cell
Generation per cell = gas charge per cell





Top Salt structure map

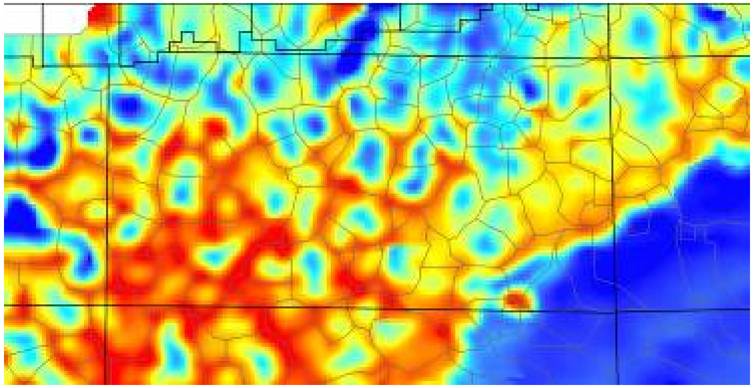
↓

Flow Direction

↓

Basin

GIS Hydrologic Tools

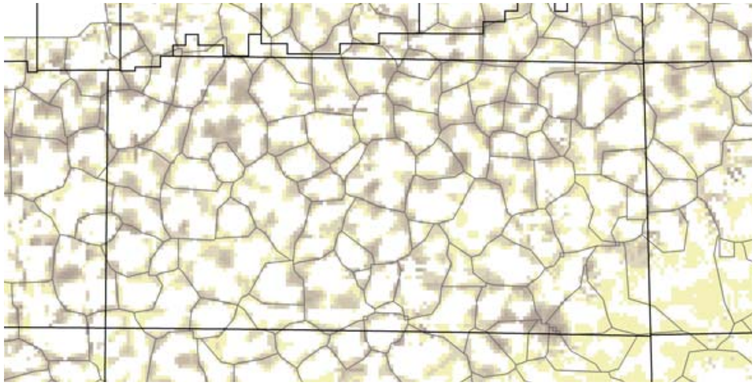


Top Salt structure with Hydrodynamic catchments

↓

Curvature

GIS tool

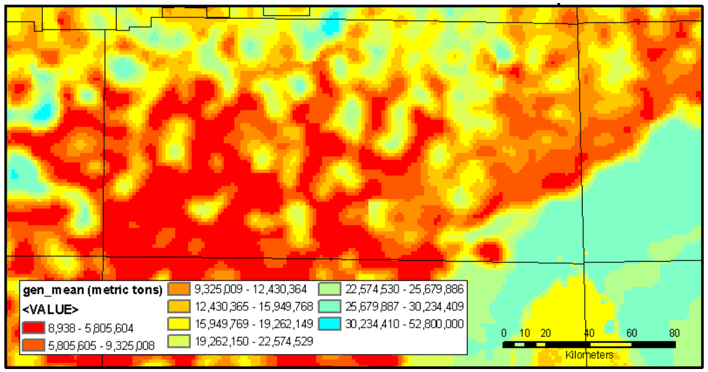


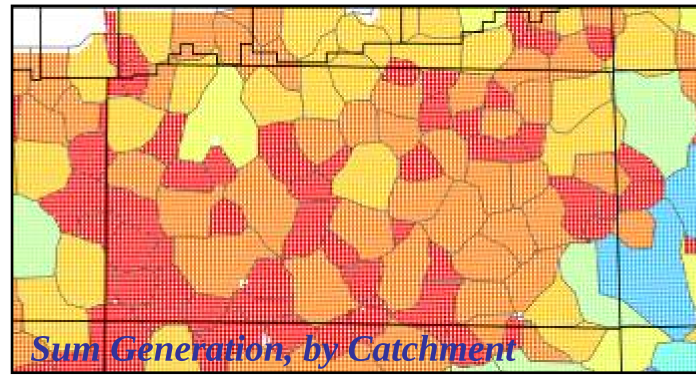
Curvature map w/ catchments

White = negative curvature
Brown = positive curvature

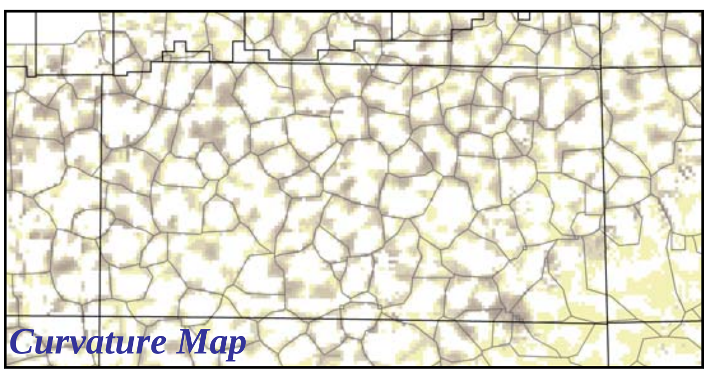
100% dip-driven migration continued …

At 100% dip migration, all gas within a catchment basin is redistributed to cells with + curvature

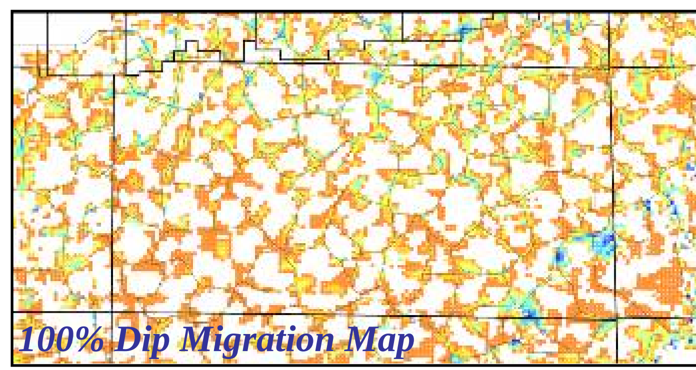




Sum Generation, by Catchment



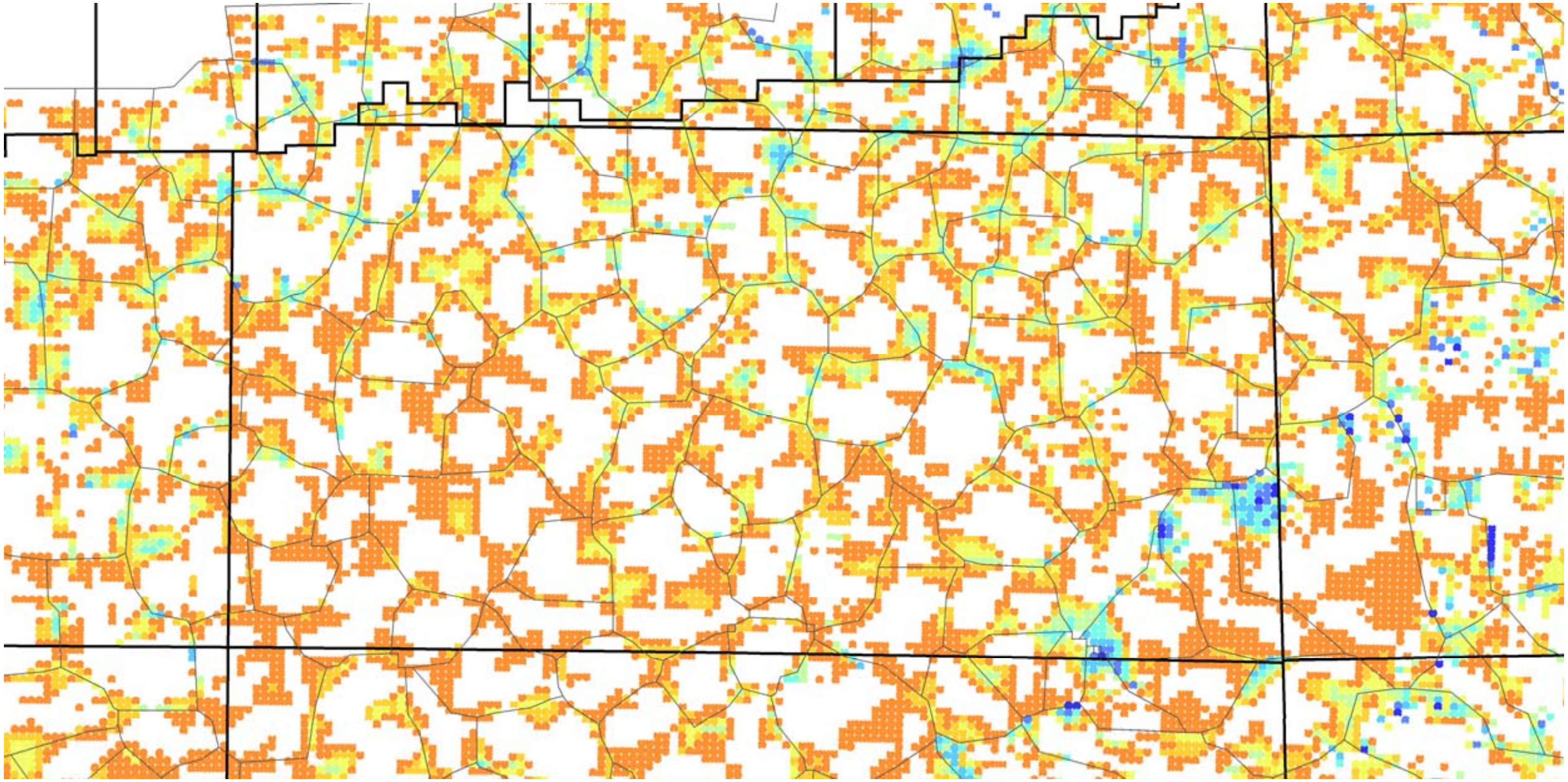
Curvature Map



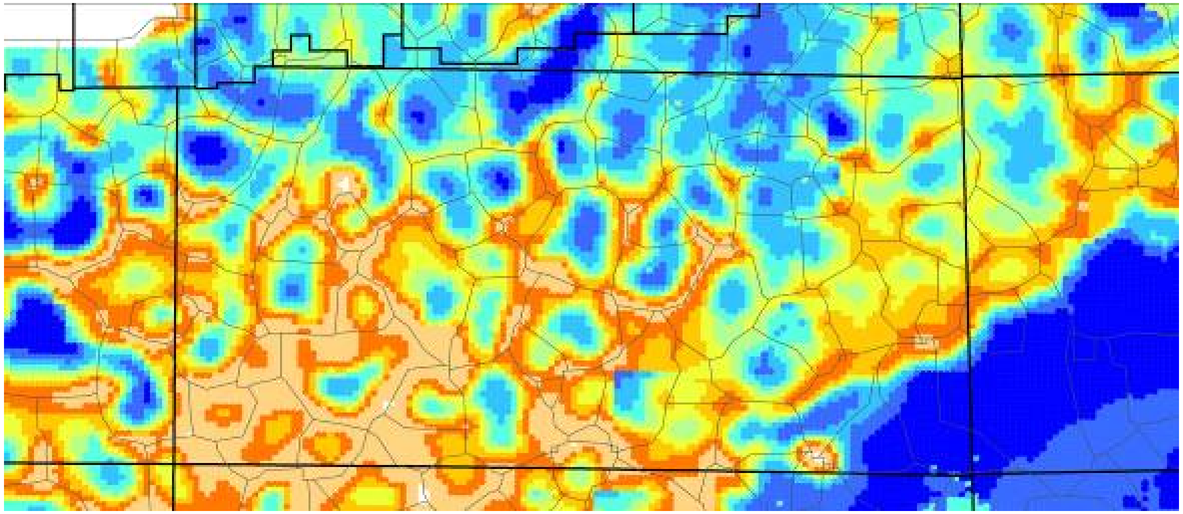
100% Dip Migration Map

100% dip-driven migration continued …

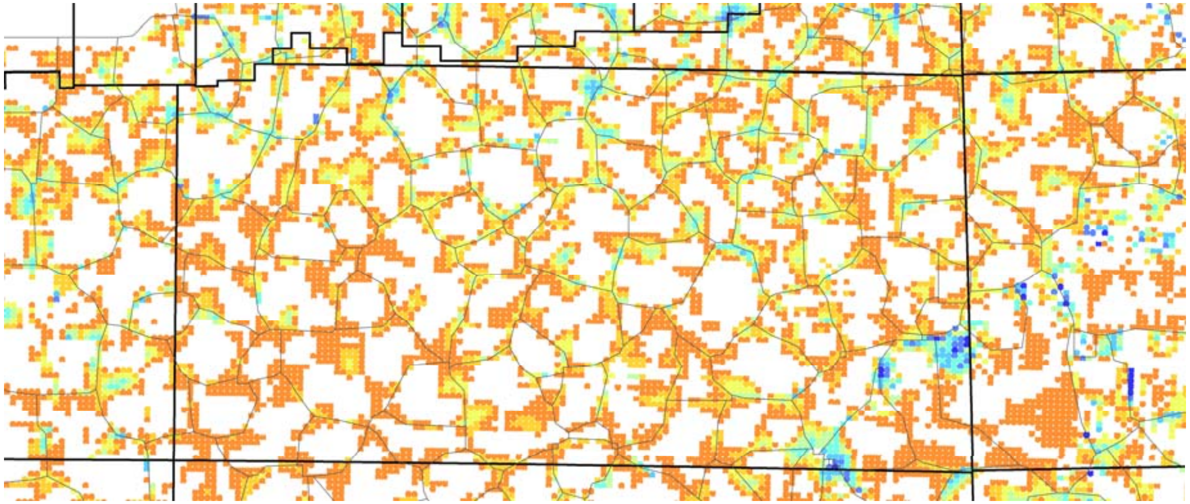
At 100% dip migration, all gas within a catchment basin is redistributed to cells with + curvature



Which migration method is correct?



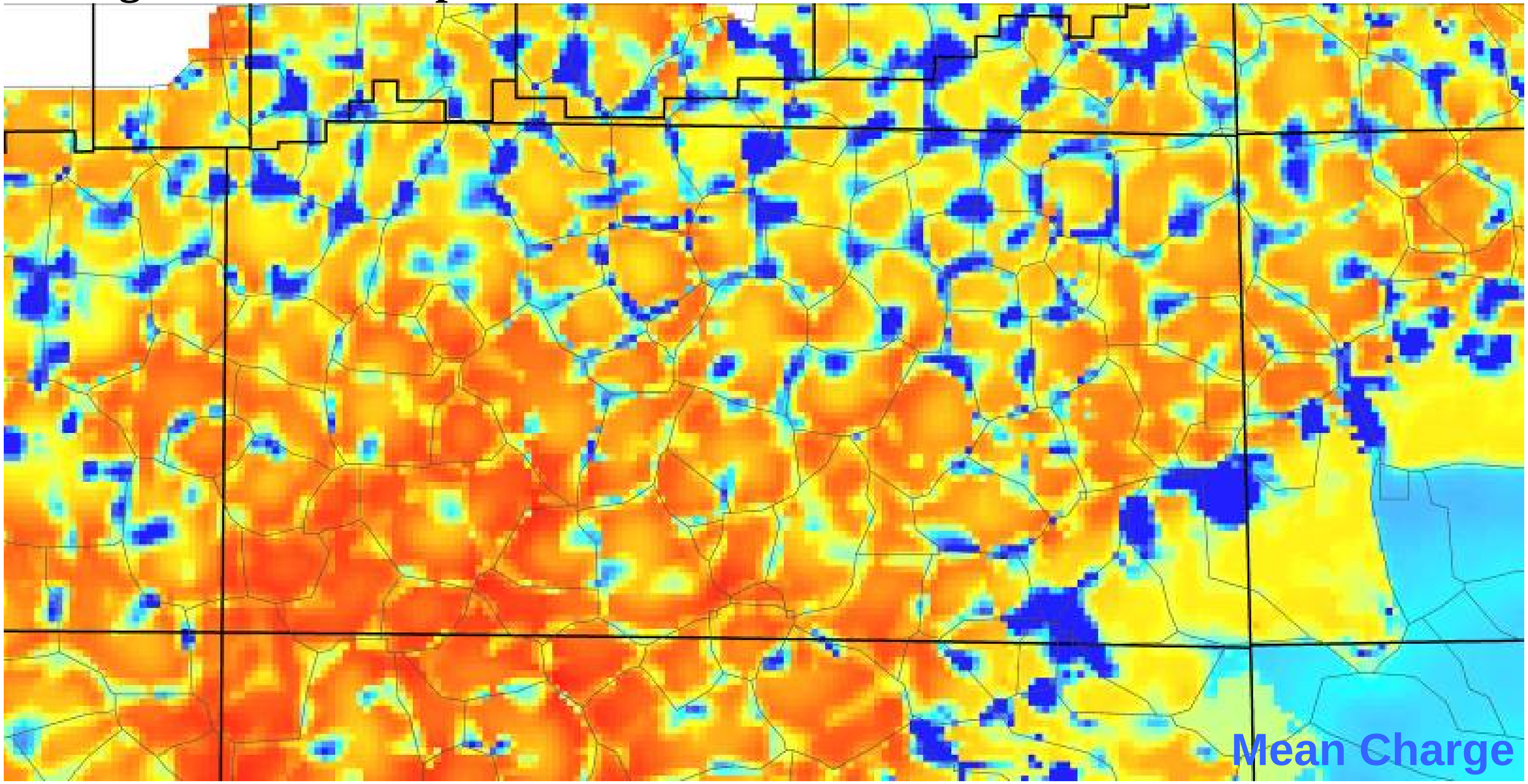
100% Vertical



100% Dip Driven

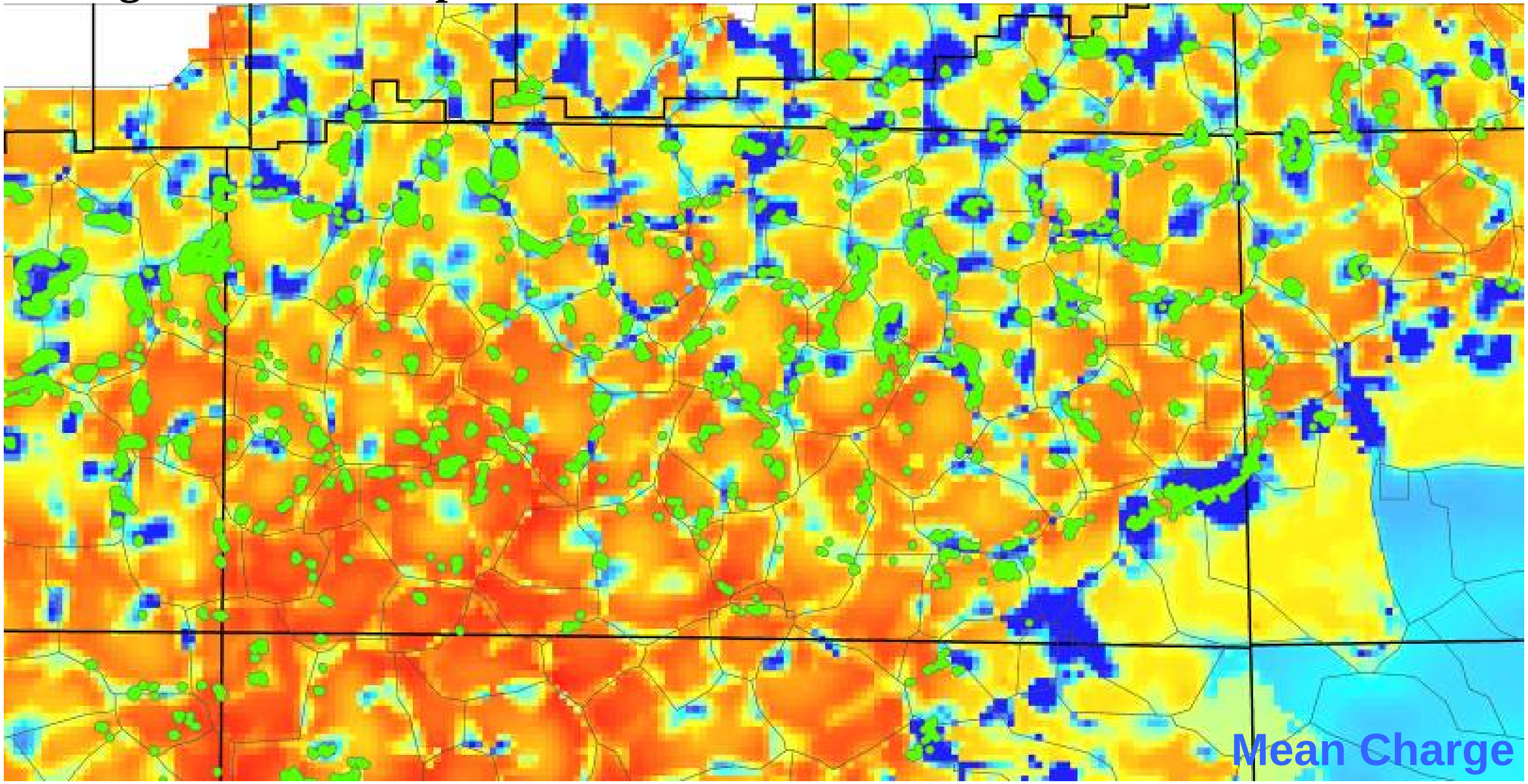
Which migration method is correct?

Mixing Ratio 60:40 dip v. vertical



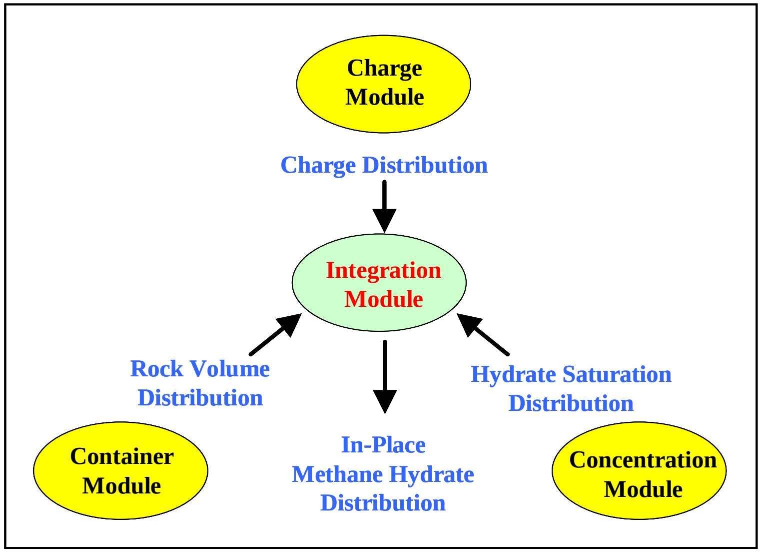
Based on sensitivity analysis using known seafloor seeps …

Mixing Ratio 60:40 dip v. vertical



Container Module

Gross HSZ - UZ = Net HSZ



Stability Equation (from Milkov and Sassen 2001)

$$f(B) = -(-9.6 \times \ln(B) + 88.4) \times C/1000 - 295.1 \times B^{-0.6} + 8.9 \times \ln(C + B) - 50.1$$

geothermal gradient: $-(-9.6 \times \ln(B) + 88.4) \times C/1000$

water bottom temperature: $295.1 \times B^{-0.6}$

phase stability expression: $8.9 \times \ln(C + B) - 50.1$

sediment temperature expression: geothermal gradient + water bottom temperature

where,

B = water depth in meters
C = thickness of the hydrate stability zone in meters

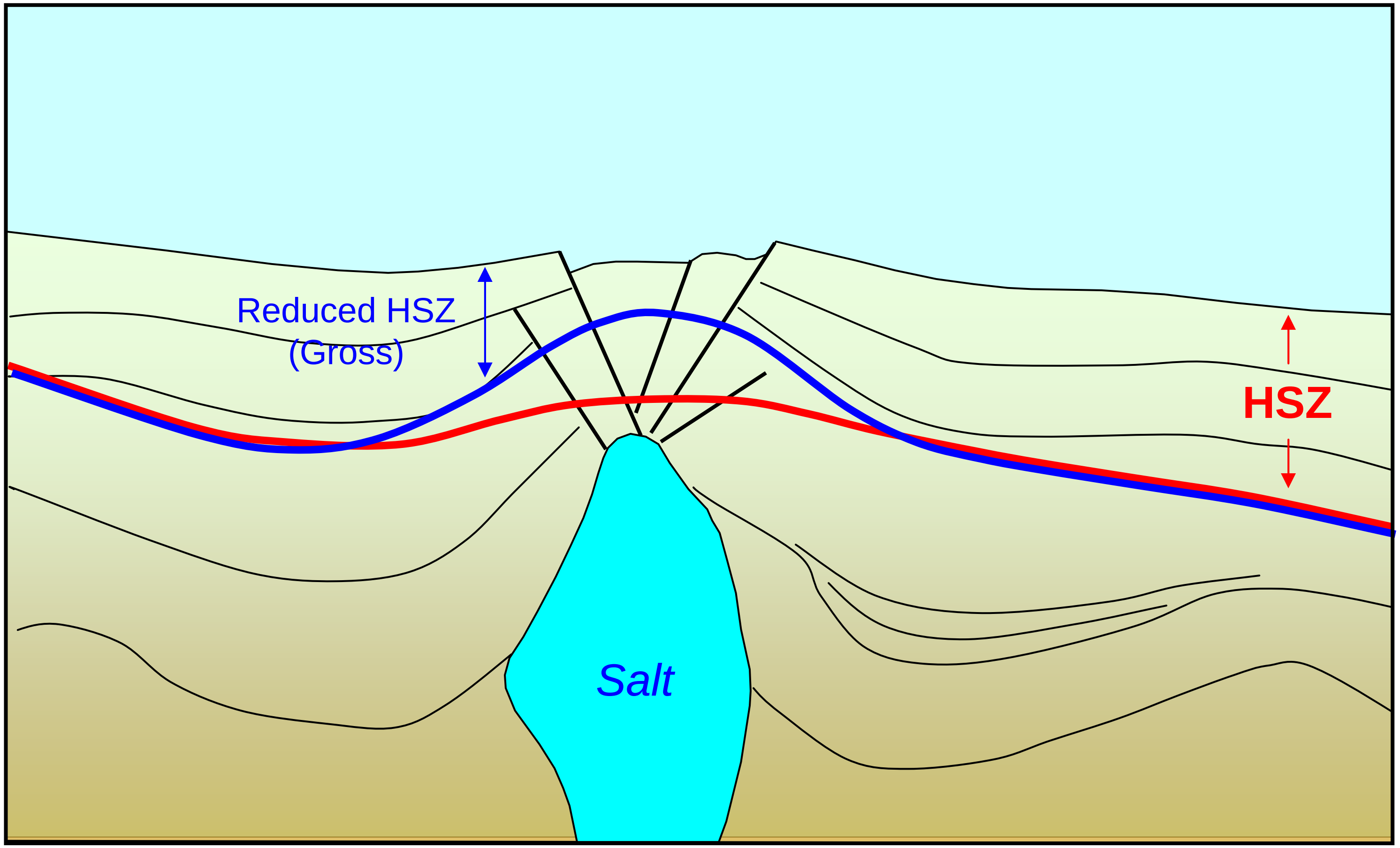
Modified: *(Stochastic)*

- **GTG / WBT**
- **Gas Composition**
  → anomaly/non-anomaly
- **Salt**

Local Salt increases:

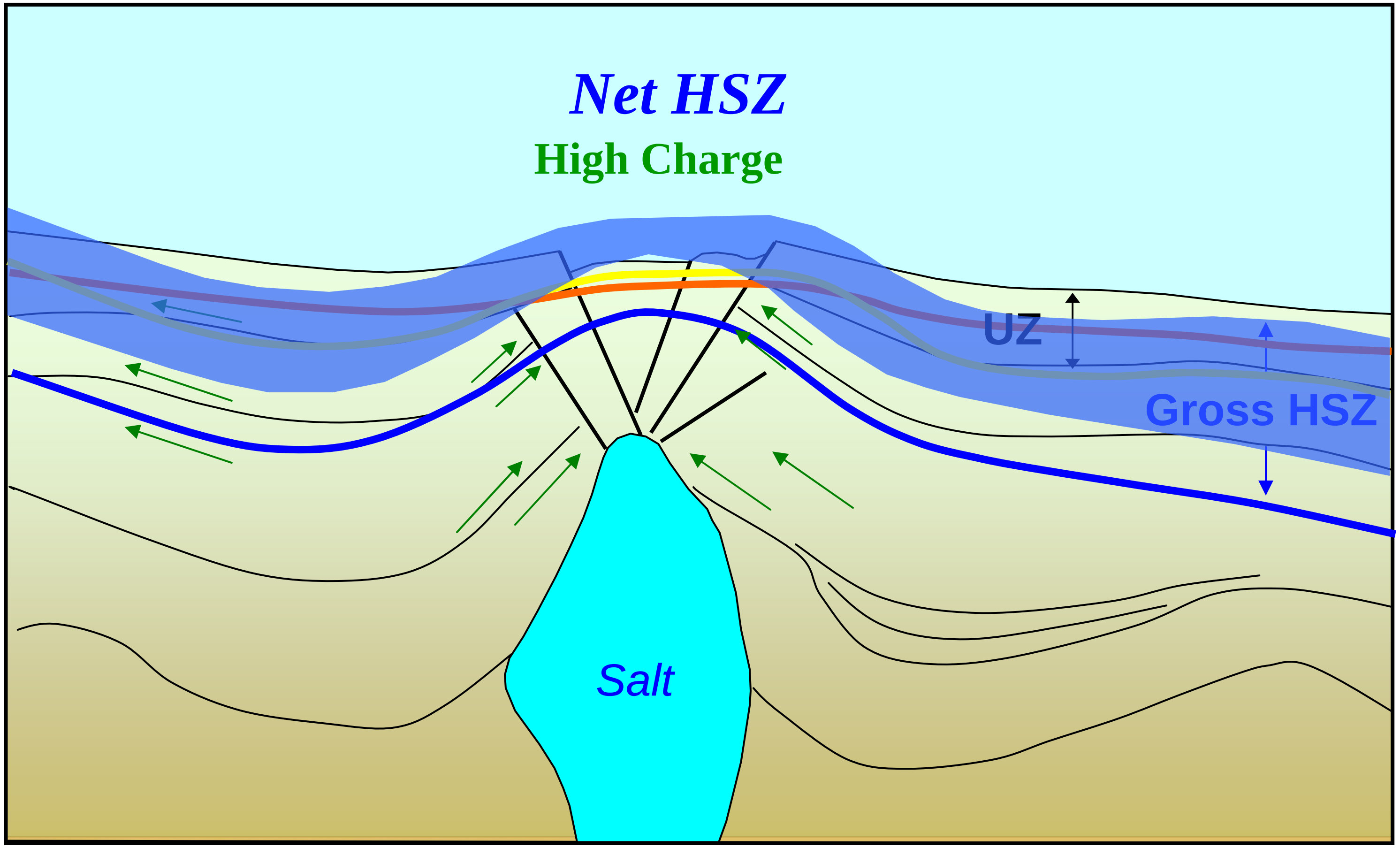
- *pore water salinity*
- *geothermal gradient*

} *Reduced HSZ thickness*

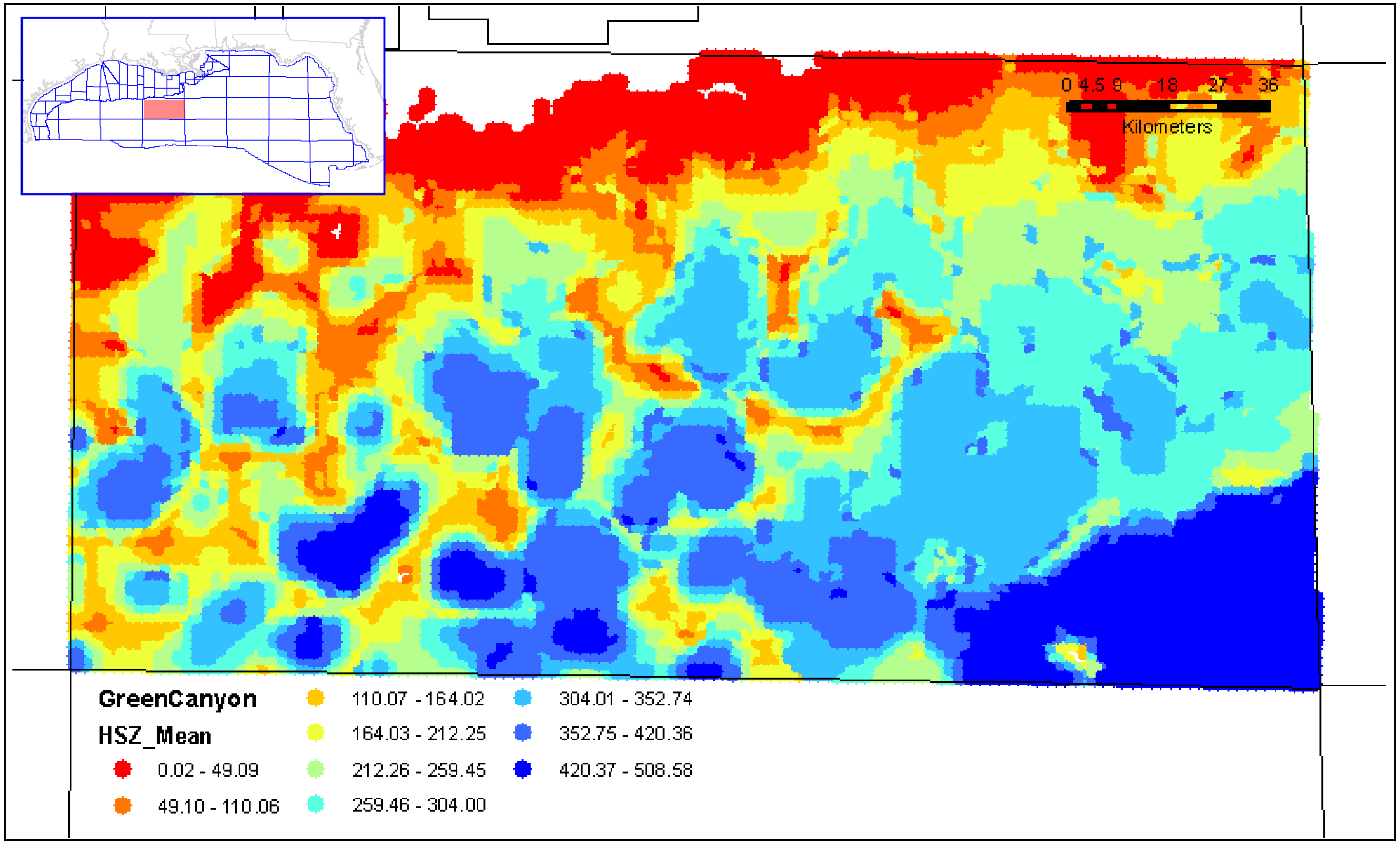


Undersaturated Zone (UZ) → ***thickness inversely related to Charge:***

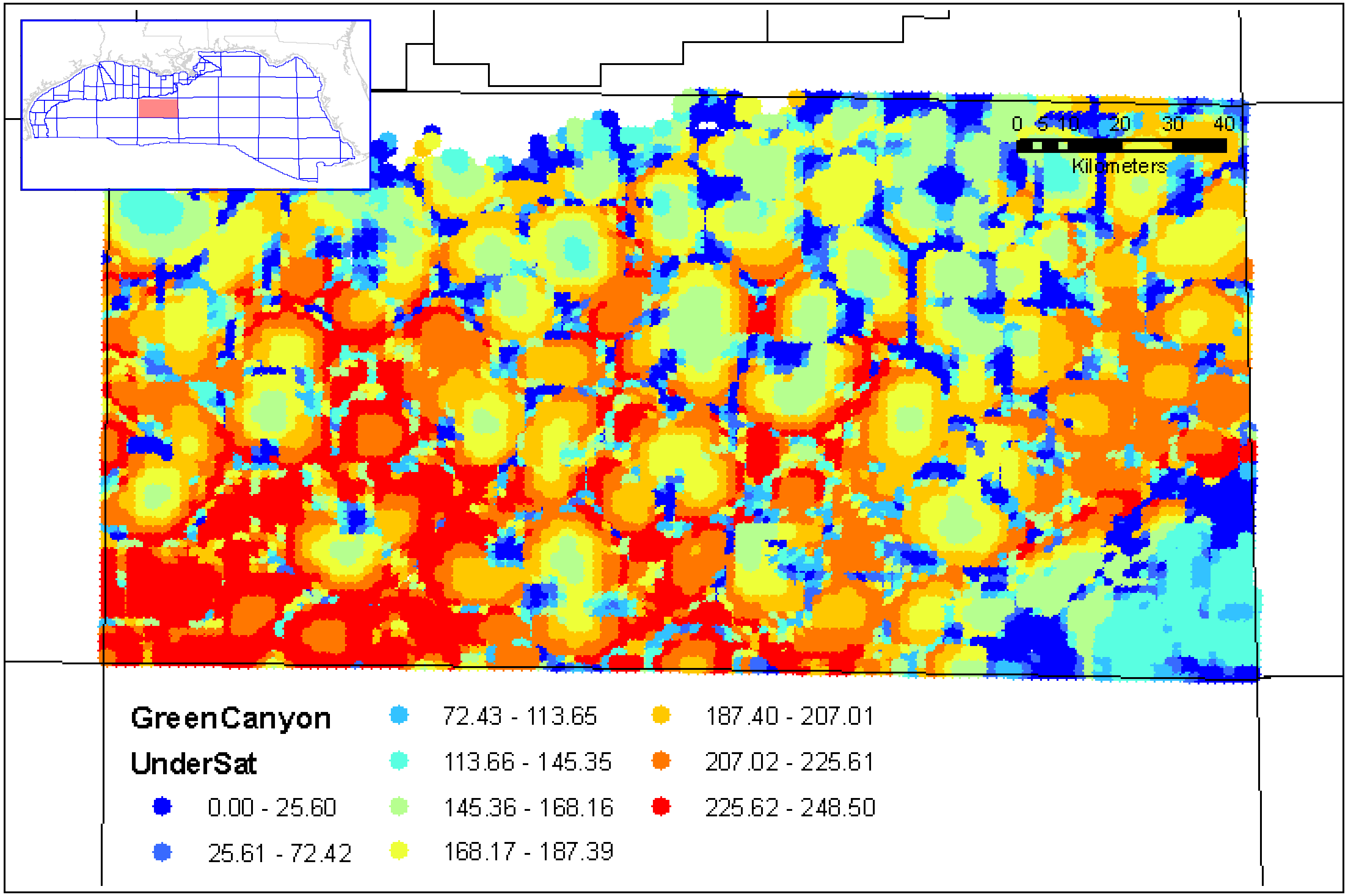
High Charge = Thin UZ *Low Charge = Thick UZ*



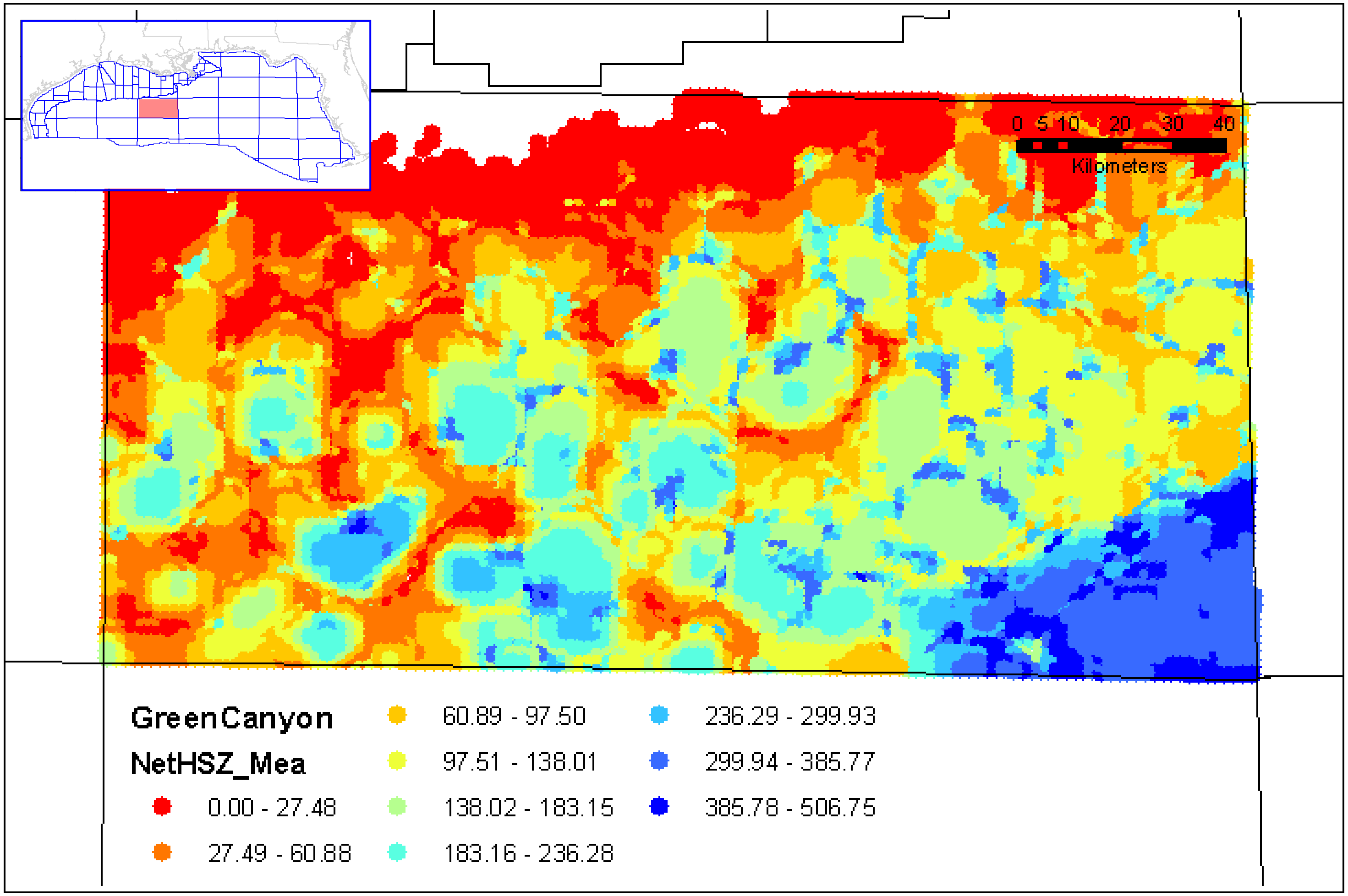
Gross HSZ


0 4.5 9 18 27 36
Kilometers
GreenCanyon
HSZ_Mean
0.02 - 49.09
49.10 - 110.06
110.07 - 164.02
164.03 - 212.25
212.26 - 259.45
259.46 - 304.00
304.01 - 352.74
352.75 - 420.36
420.37 - 508.58

Undersaturated Zone (UZ)



Net HSZ (= Gross HSZ – UZ)

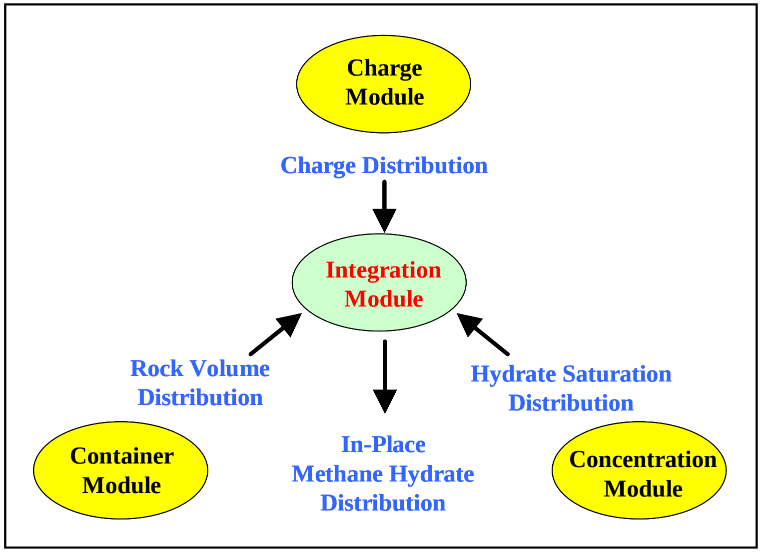


Concentration Module

HSZ porosity, by lithologic facies

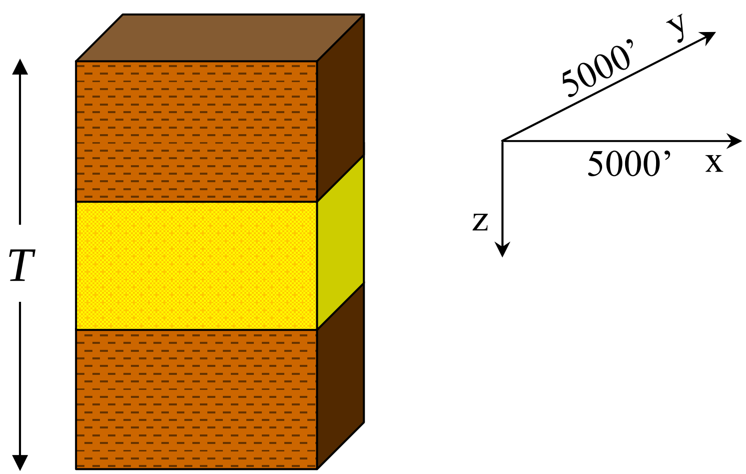
↓

Pore space saturated by gas hydrate



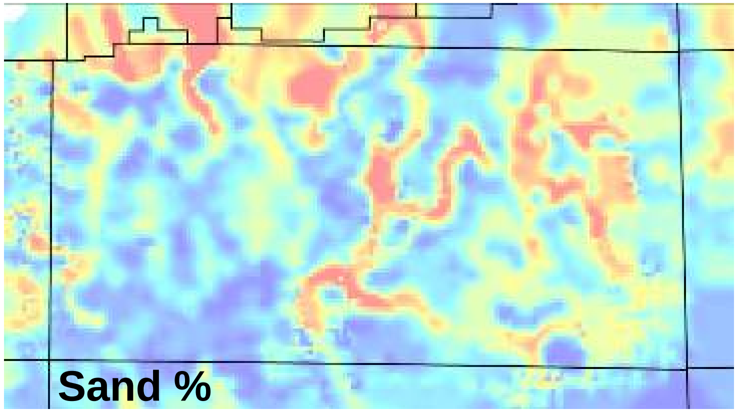
Sand Void = (Volume)(Porosity)
Volume Sand = (x)(y)[(*T*)(sand%)]
Porosity Sand = *f*(*d*)

Shale Void = (Volume)(Porosity)
Volume Shale = (x)(y)[(*T*)(1-sand%)]
Porosity Shale = *f*(*d*)

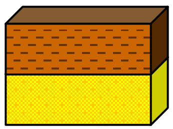


From Container Module:
(*T*) Net HSZ thickness
(*d*) Midpoint depth net HSZ

From input file:
sand %



% GH saturation of pore space

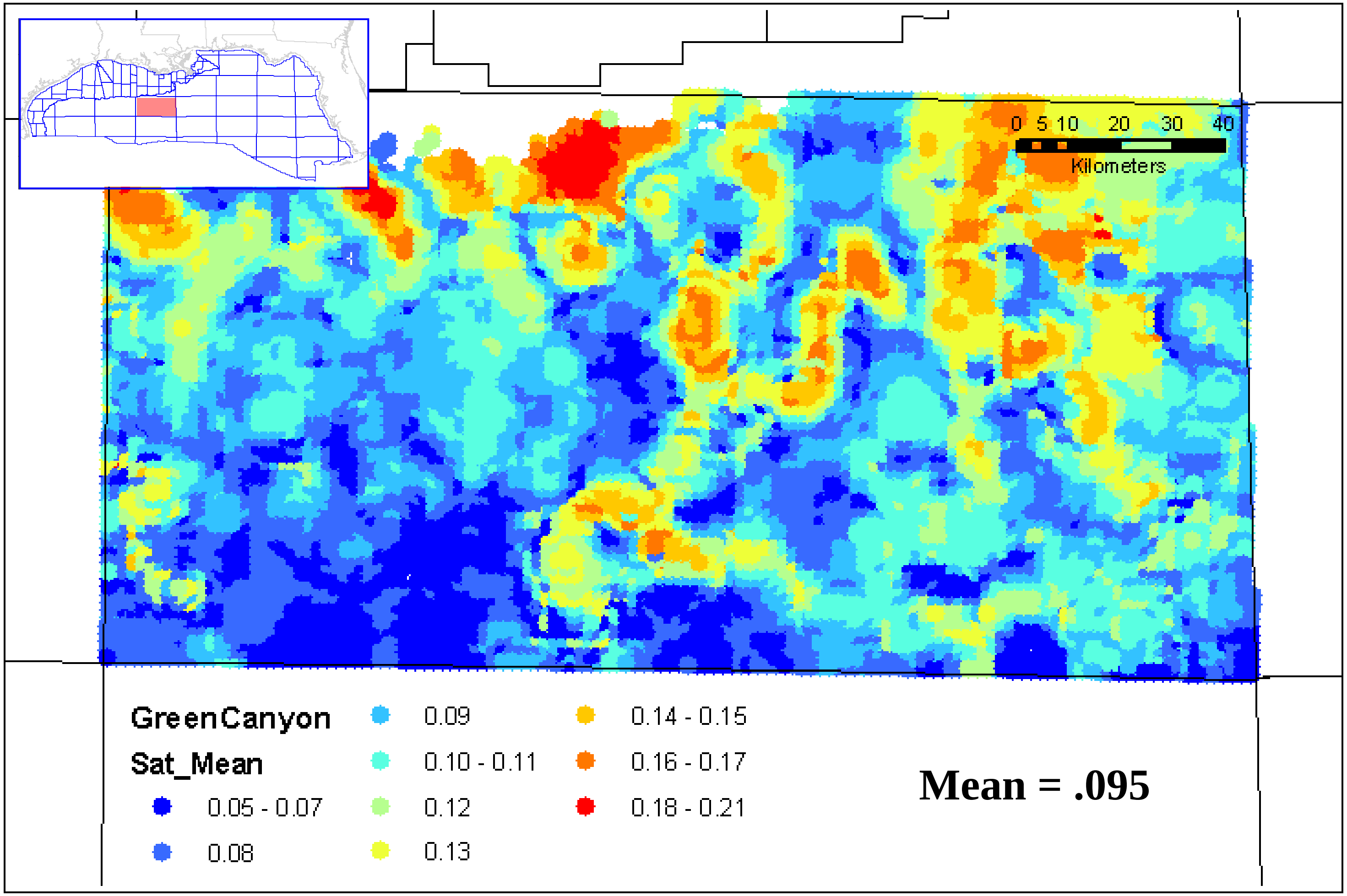


Void Space	Minimum	Most Likely	Maximum
Shale matrix	0	10	20
Sand matrix	40	60	90

Mallik M5L38, AT13, AT14, BR-994, BR-995, HR1247, HR1248, and HR1251

Sand and Shale are combined to provide a single concentration value (expressed as a % of bulk rock volume)

Concentration

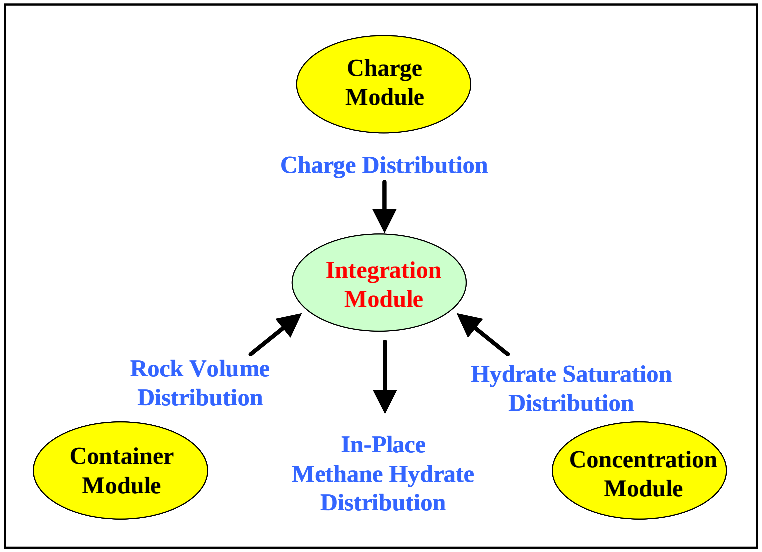


Integration Module

Integrate Module Results

↓

Convert



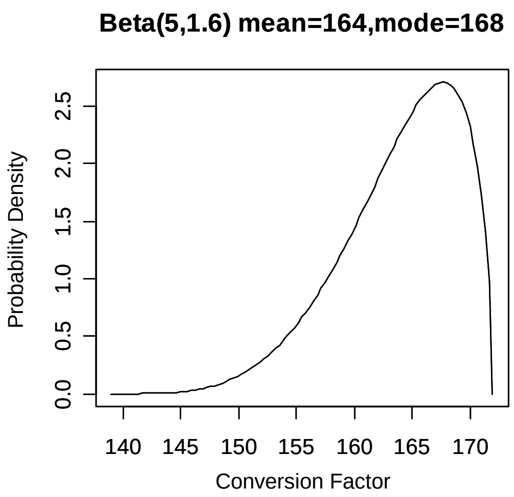
Integration Module

For each model cell, we:

•Compare charge to available container ⟶ retain smaller of two

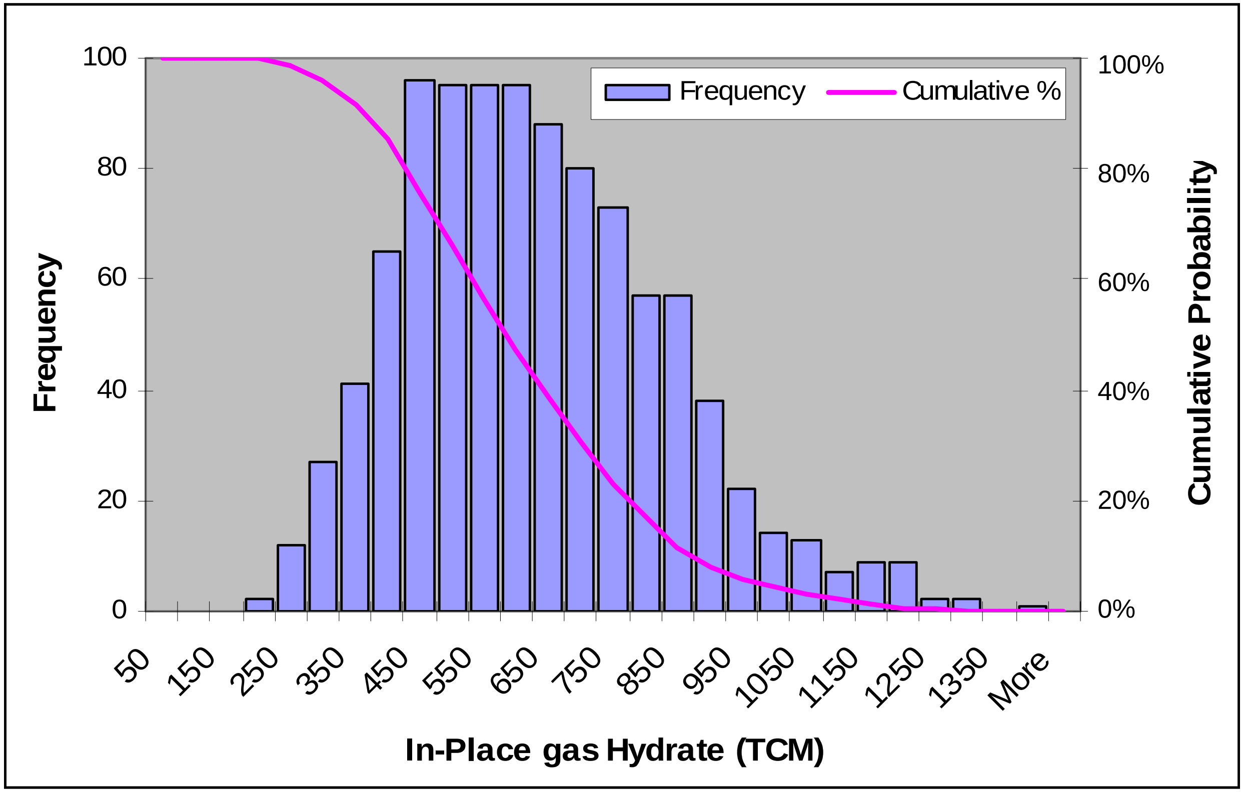
•*Except* at surficial anomalies ⟶ manually fill if undercharged

•Convert from RTP to STP:

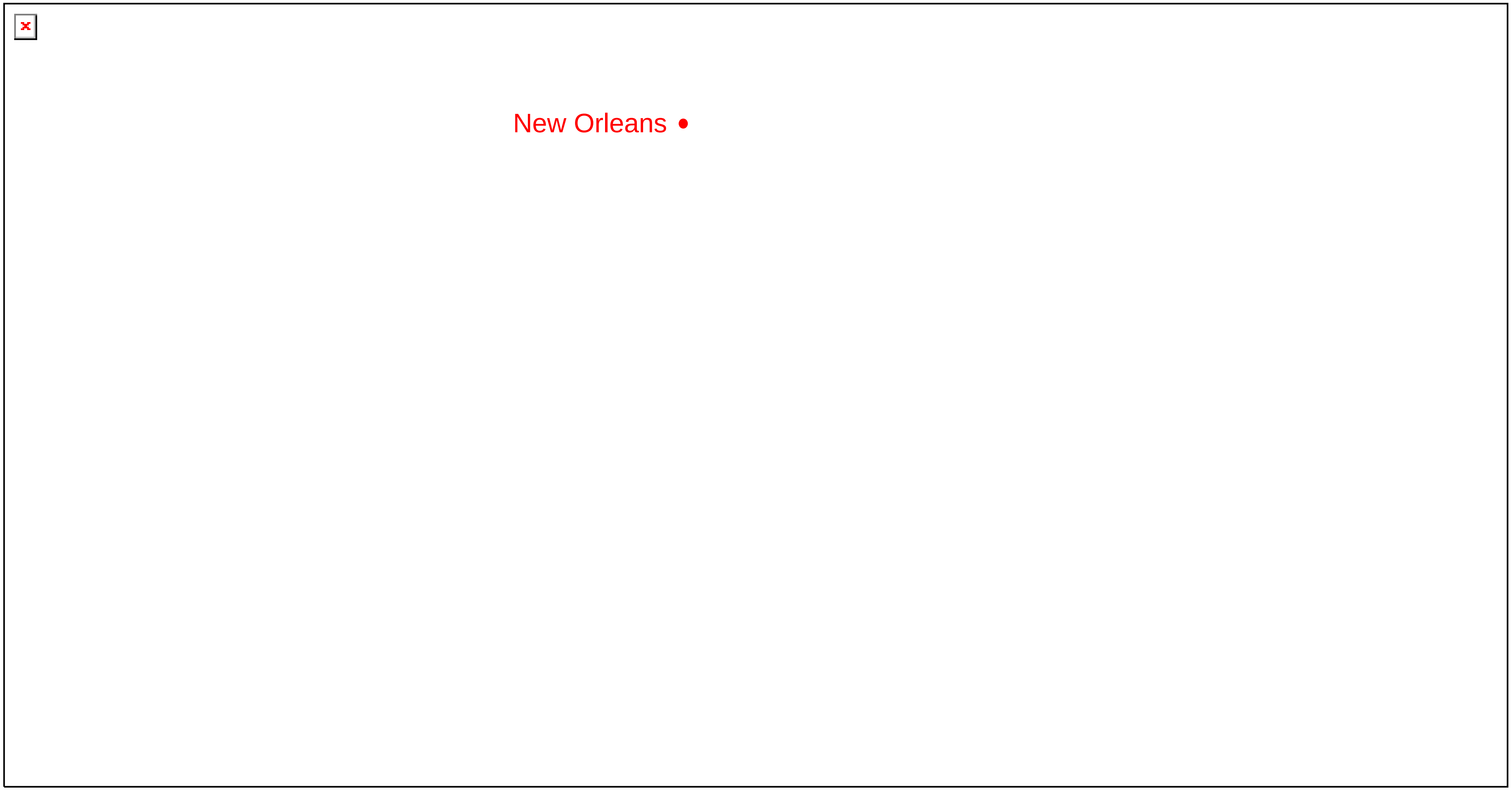


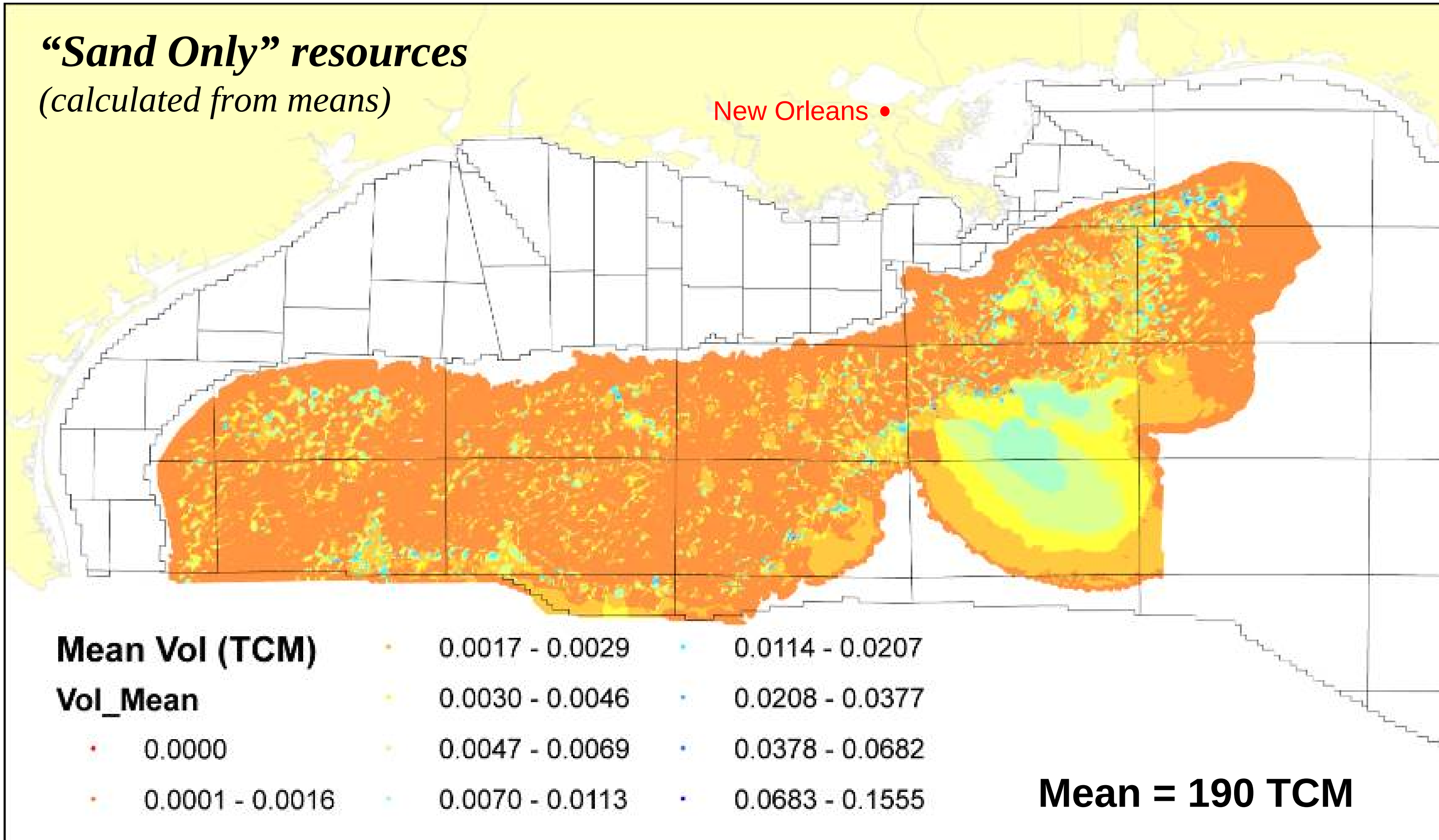
In–Place Results

U.S. GOM In-Place Results (1,000 trials)

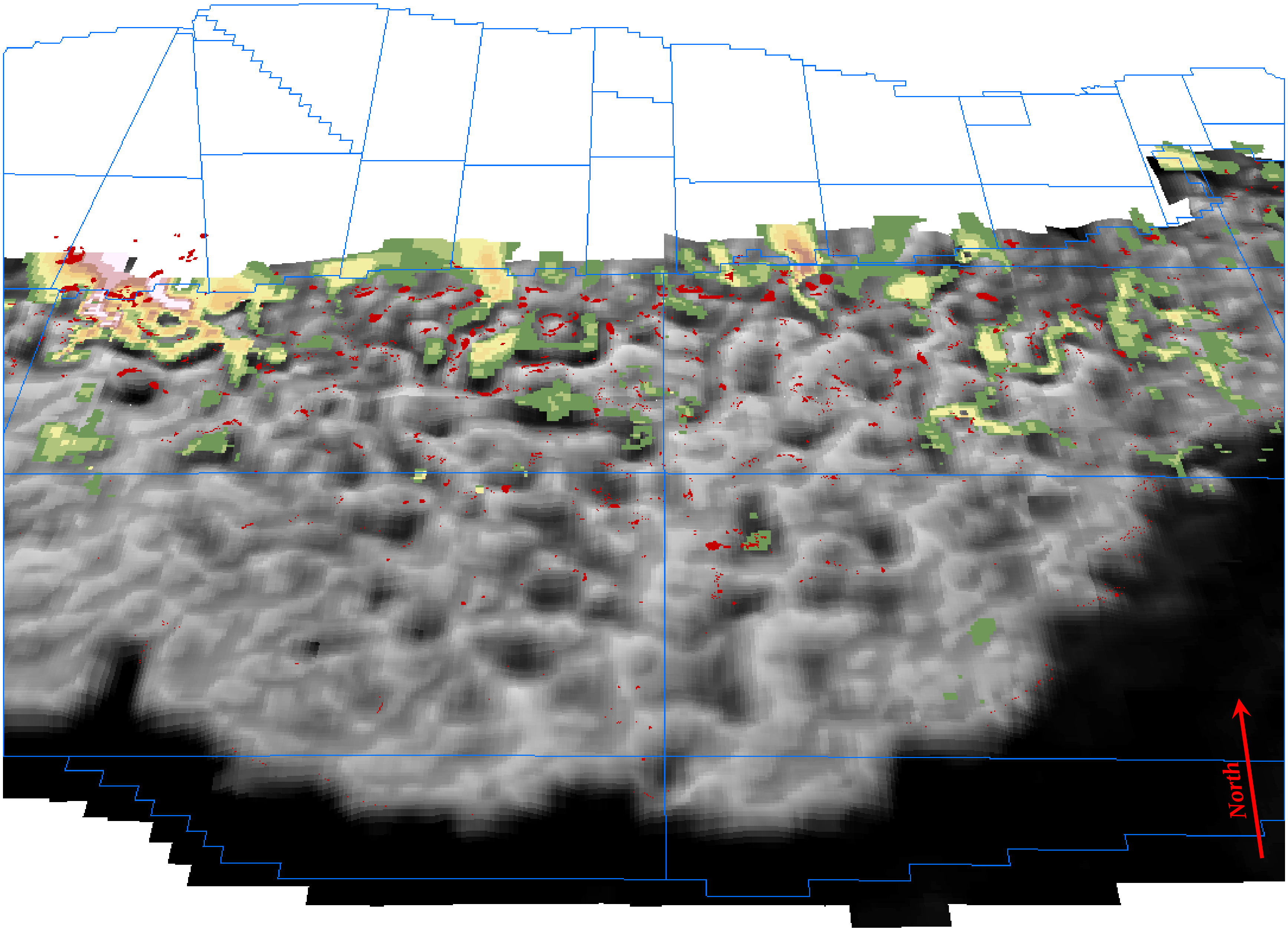


Mean Total = 607 TCM *(21,444 TCF)*

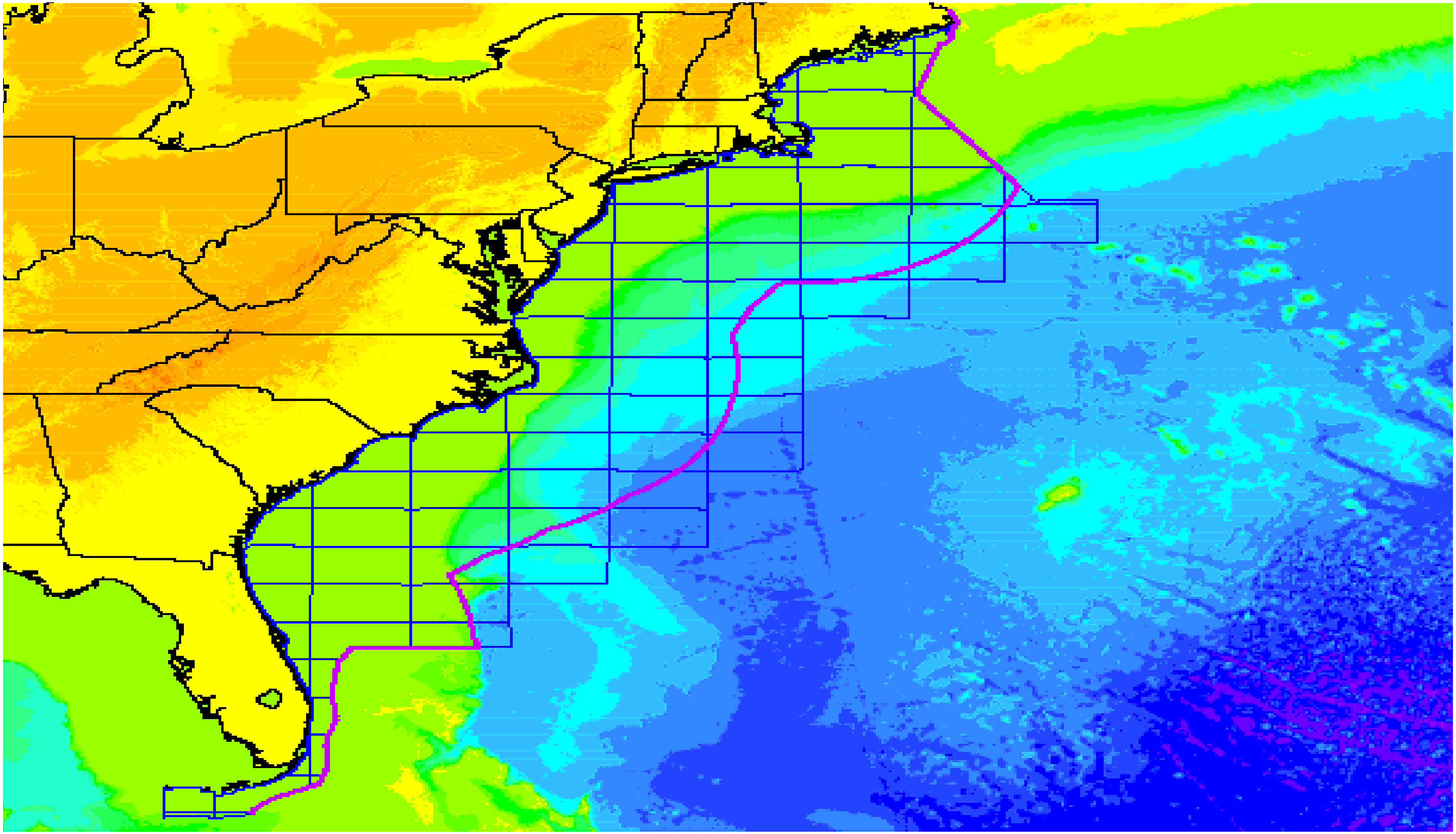

New Orleans

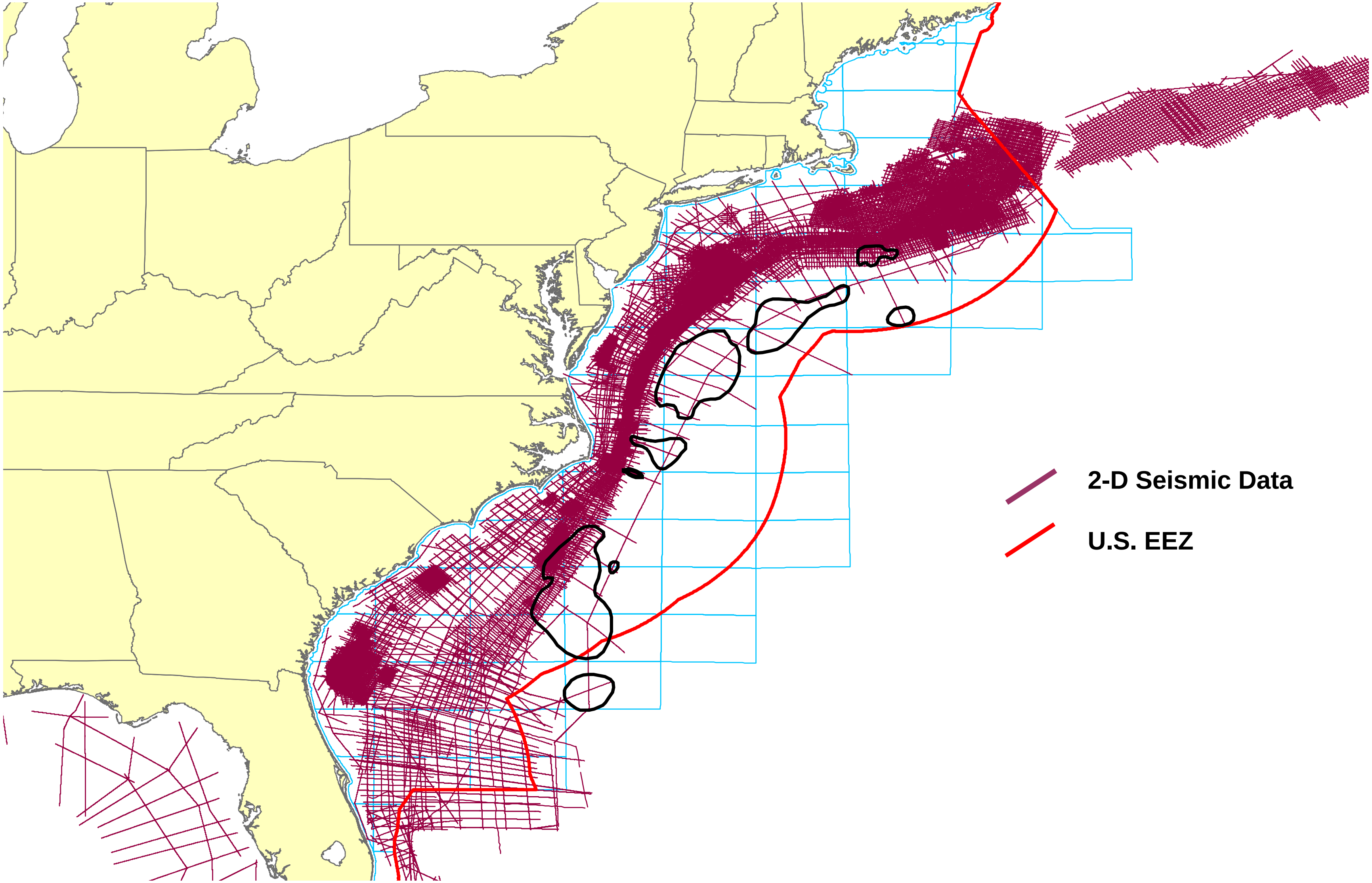


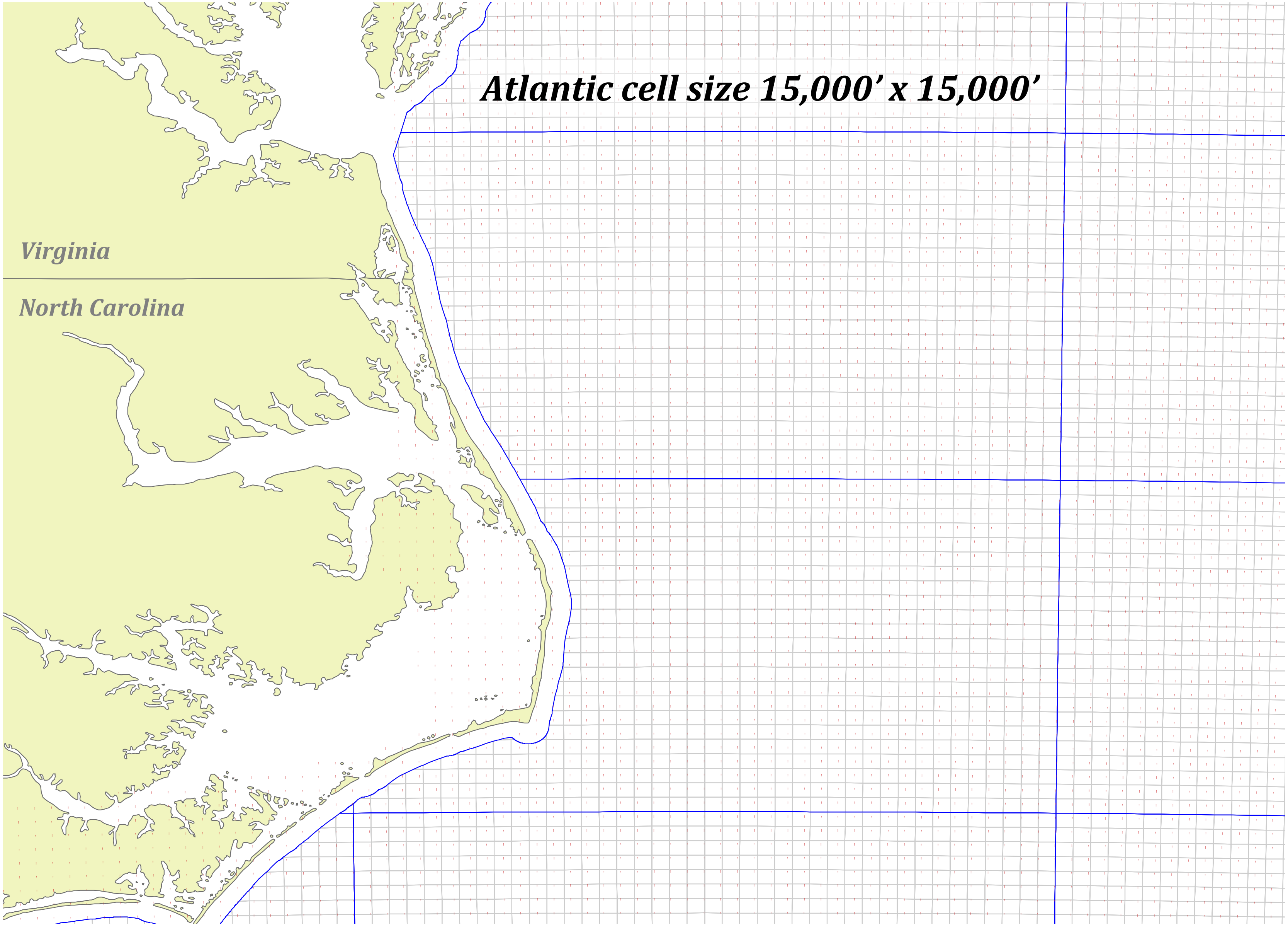
"Sand Only" resources
(calculated from means)
New Orleans
Mean Vol (TCM)
Vol_Mean
0.0000
0.0001 - 0.0016
0.0017 - 0.0029
0.0030 - 0.0046
0.0047 - 0.0069
0.0070 - 0.0113
0.0114 - 0.0207
0.0208 - 0.0377
0.0378 - 0.0682
0.0683 - 0.1555
Mean = 190 TCM

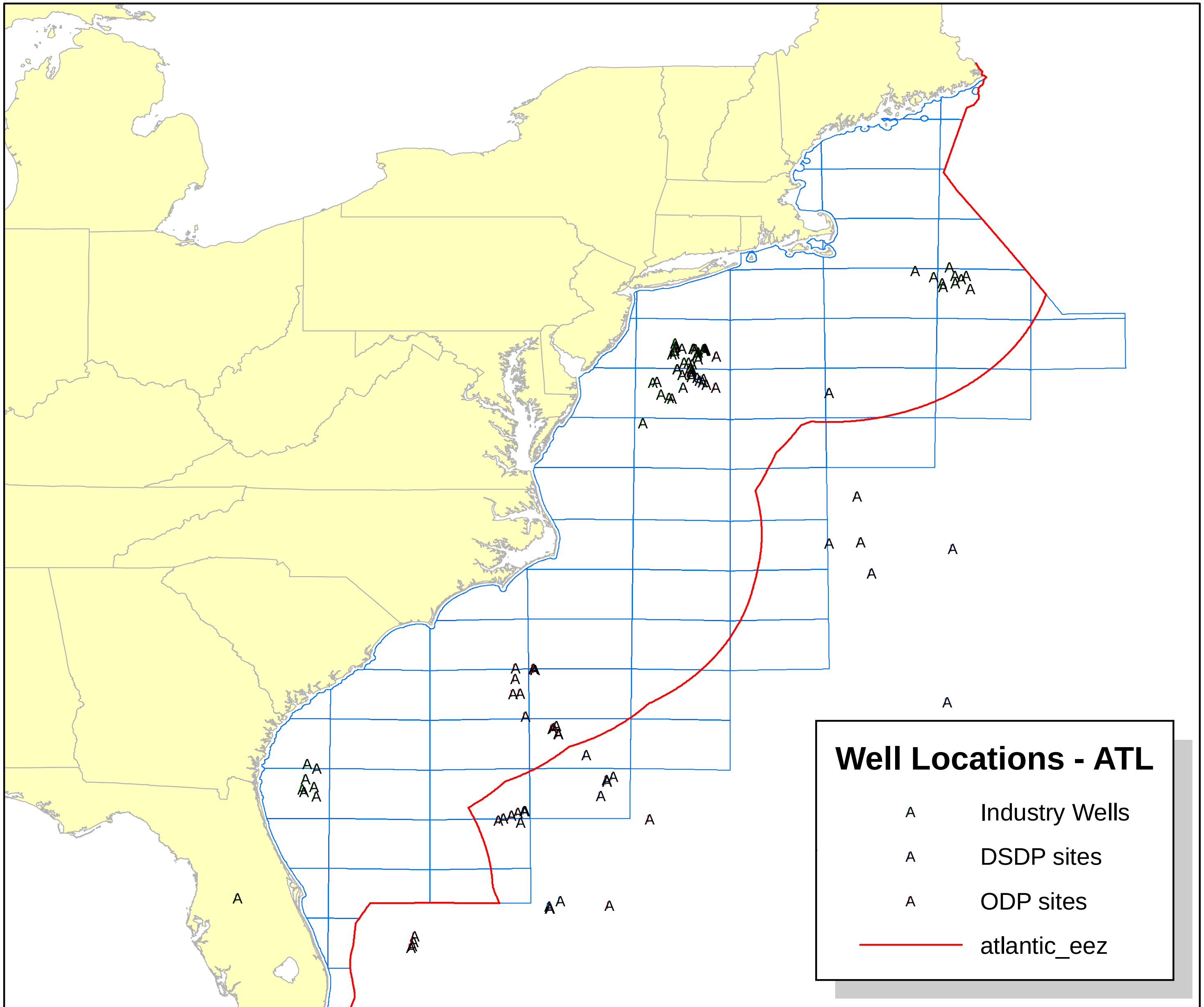

North

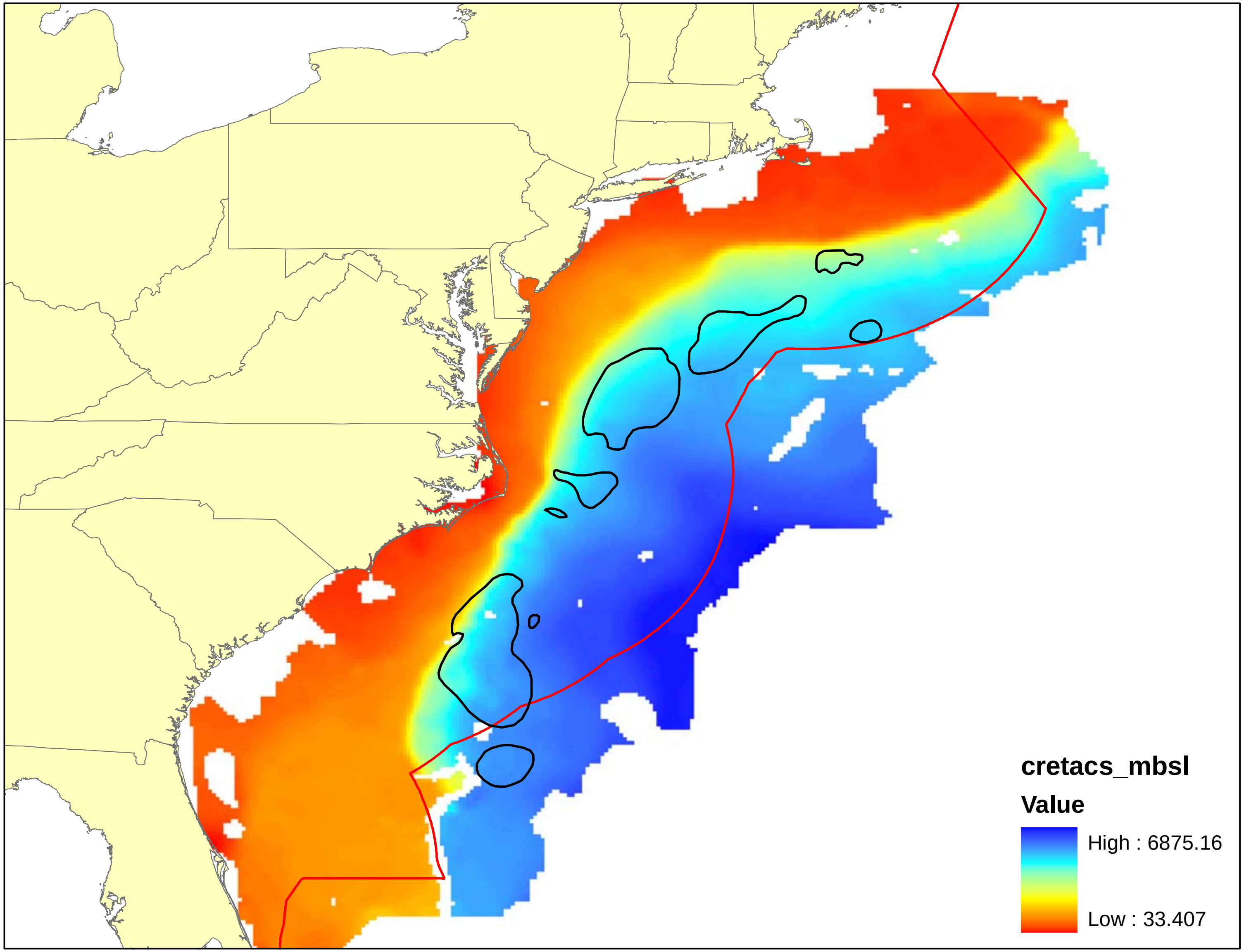
Atlantic OCS

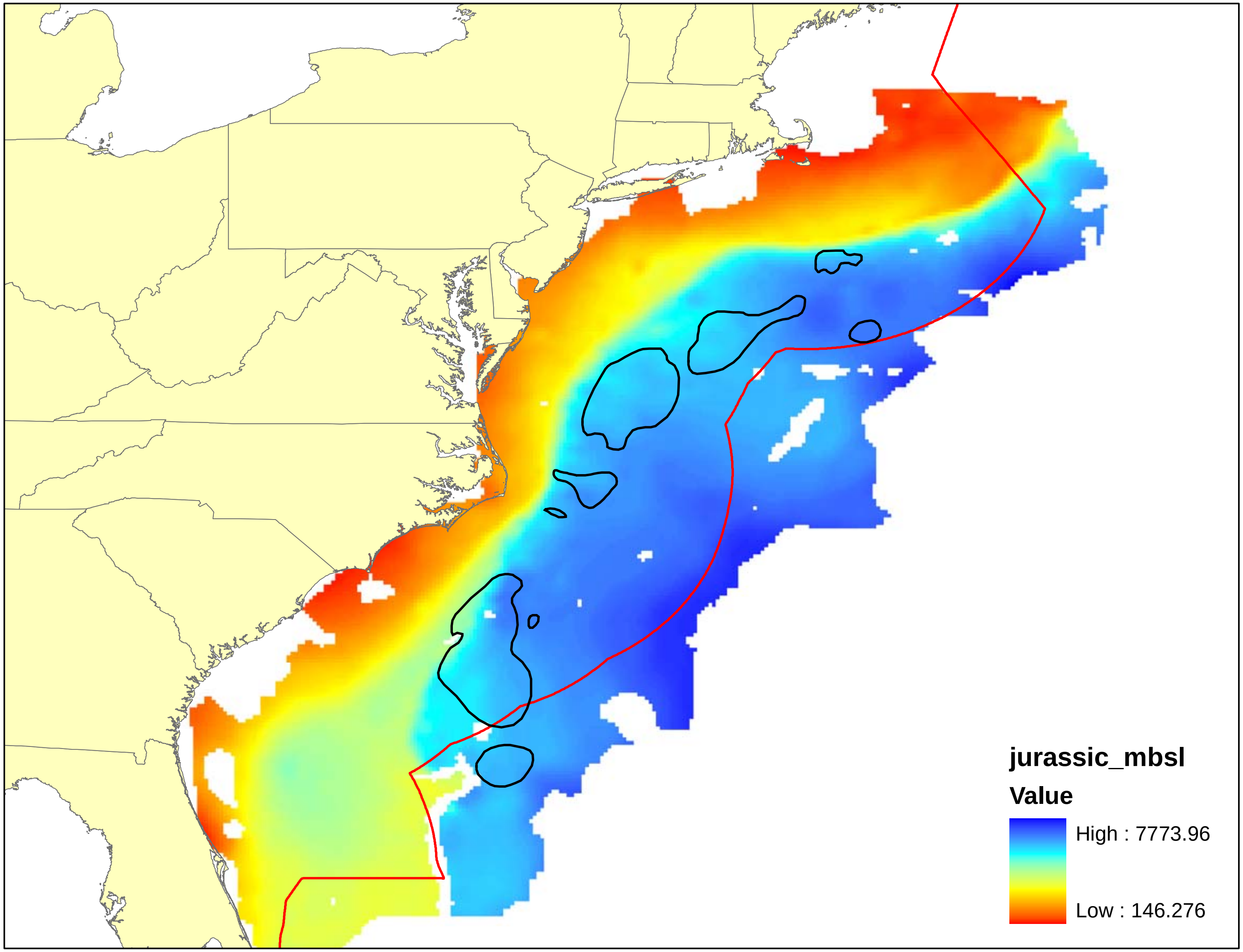


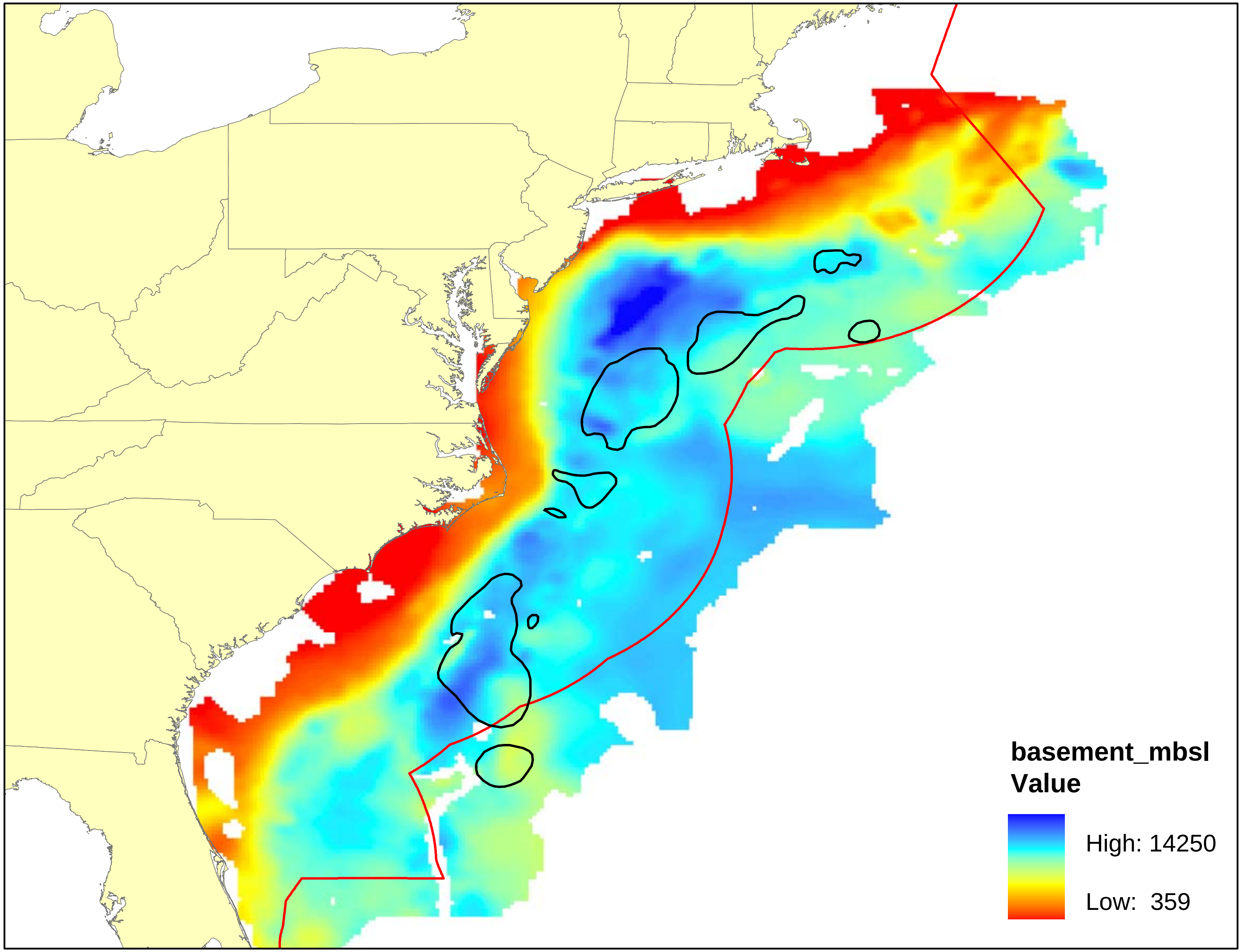

2-D Seismic Data
U.S. EEZ

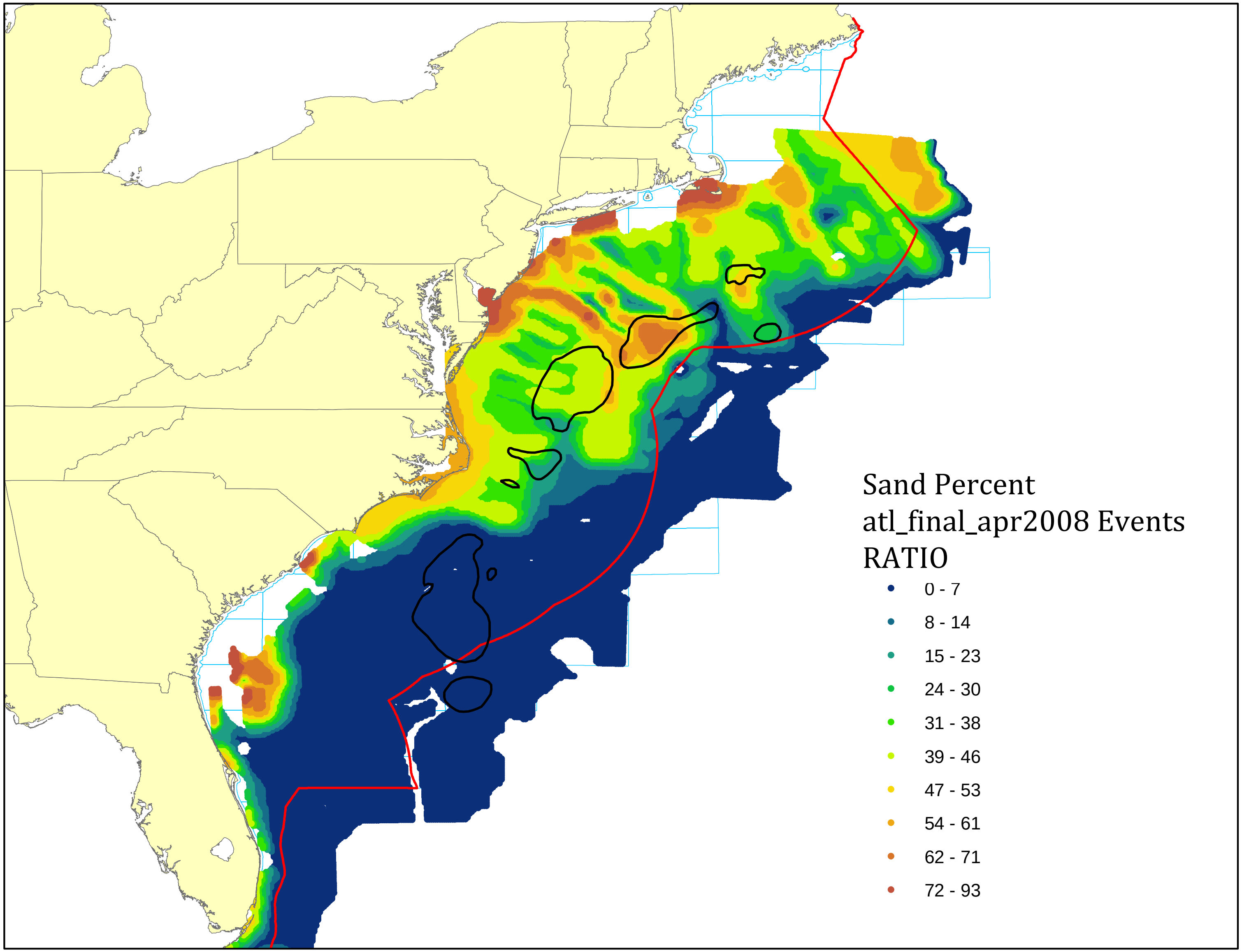

Atlantic cell size 15,000' x 15,000'
Virginia
North Carolina

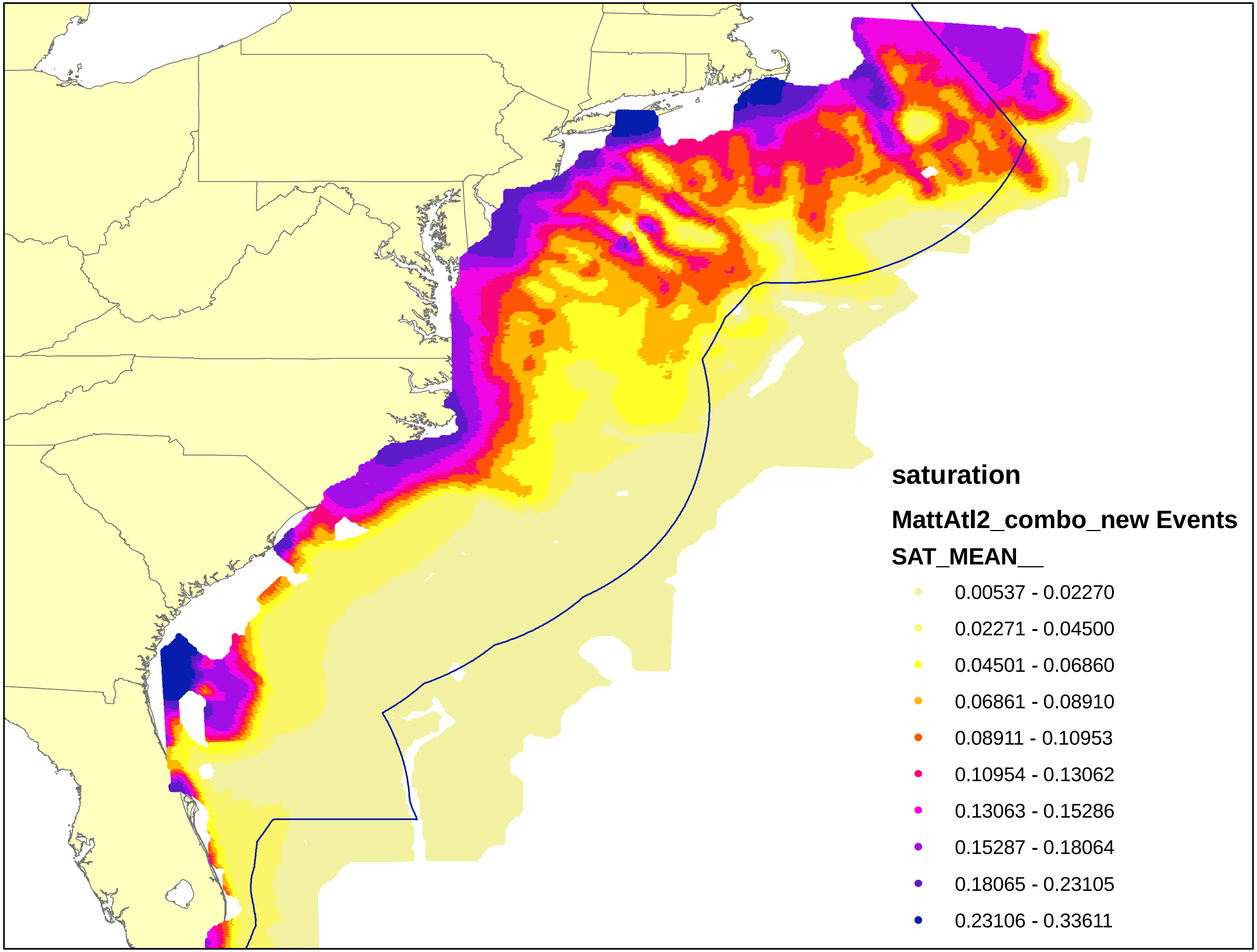

Well Locations - ATL
Industry Wells
DSDP sites
ODP sites
atlantic_eez

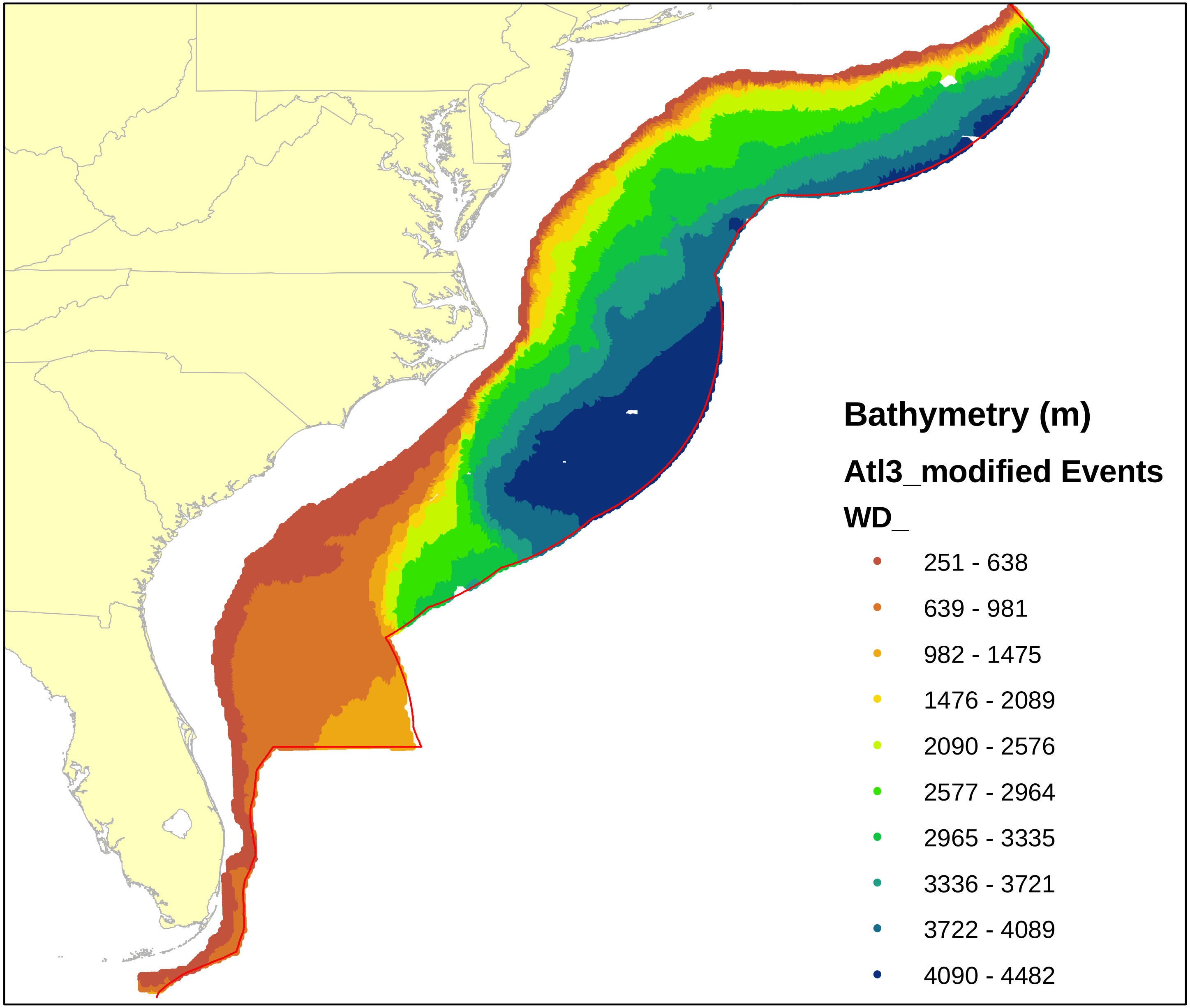

cretacs_mbsl
Value
High : 6875.16
Low : 33.407

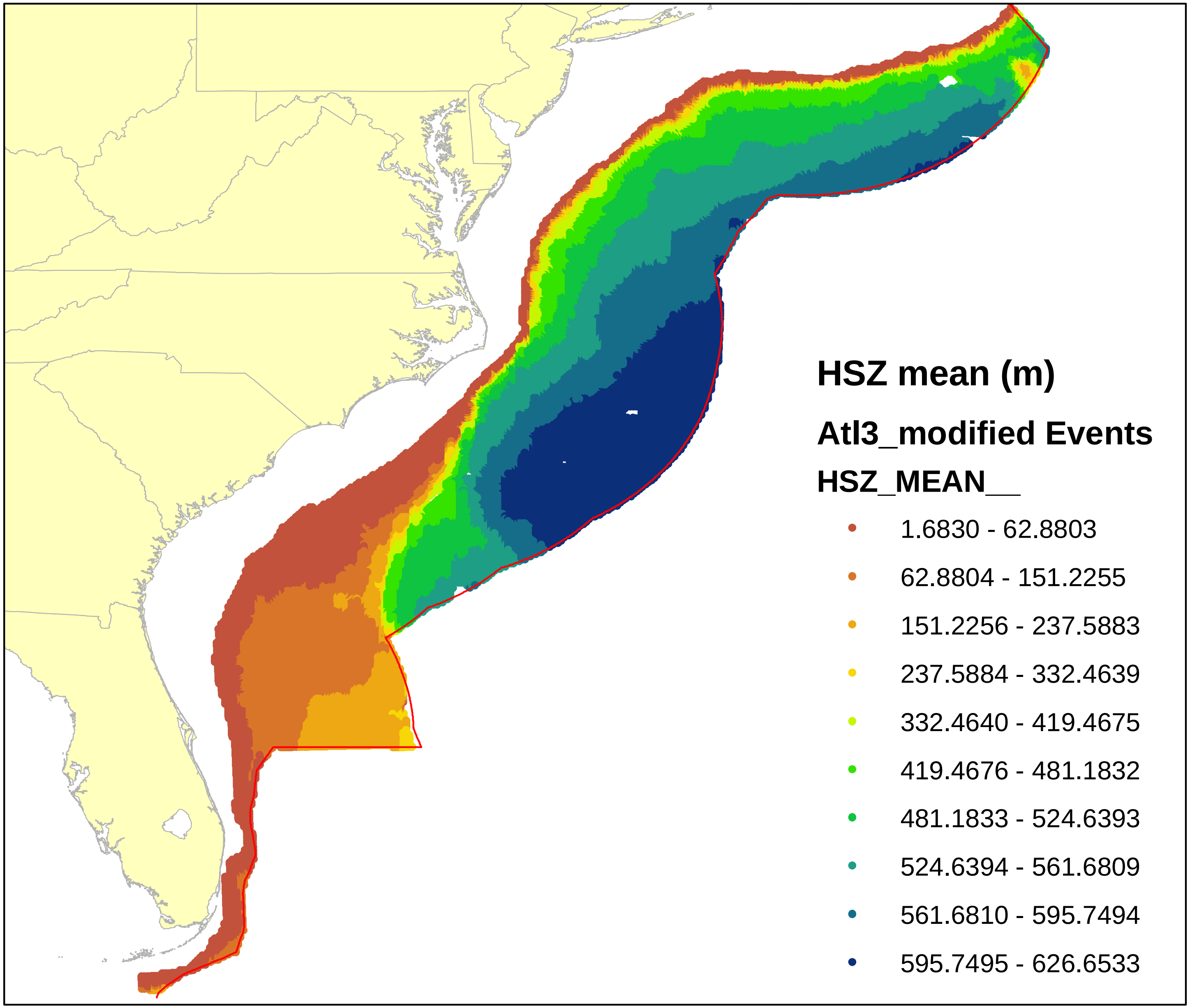

jurassic_mbsl
Value
High : 7773.96
Low : 146.276


basement_mbsl
Value
High: 14250
Low: 359


Sand Percent
atl_final_apr2008 Events
RATIO
0 - 7
8 - 14
15 - 23
24 - 30
31 - 38
39 - 46
47 - 53
54 - 61
62 - 71
72 - 93

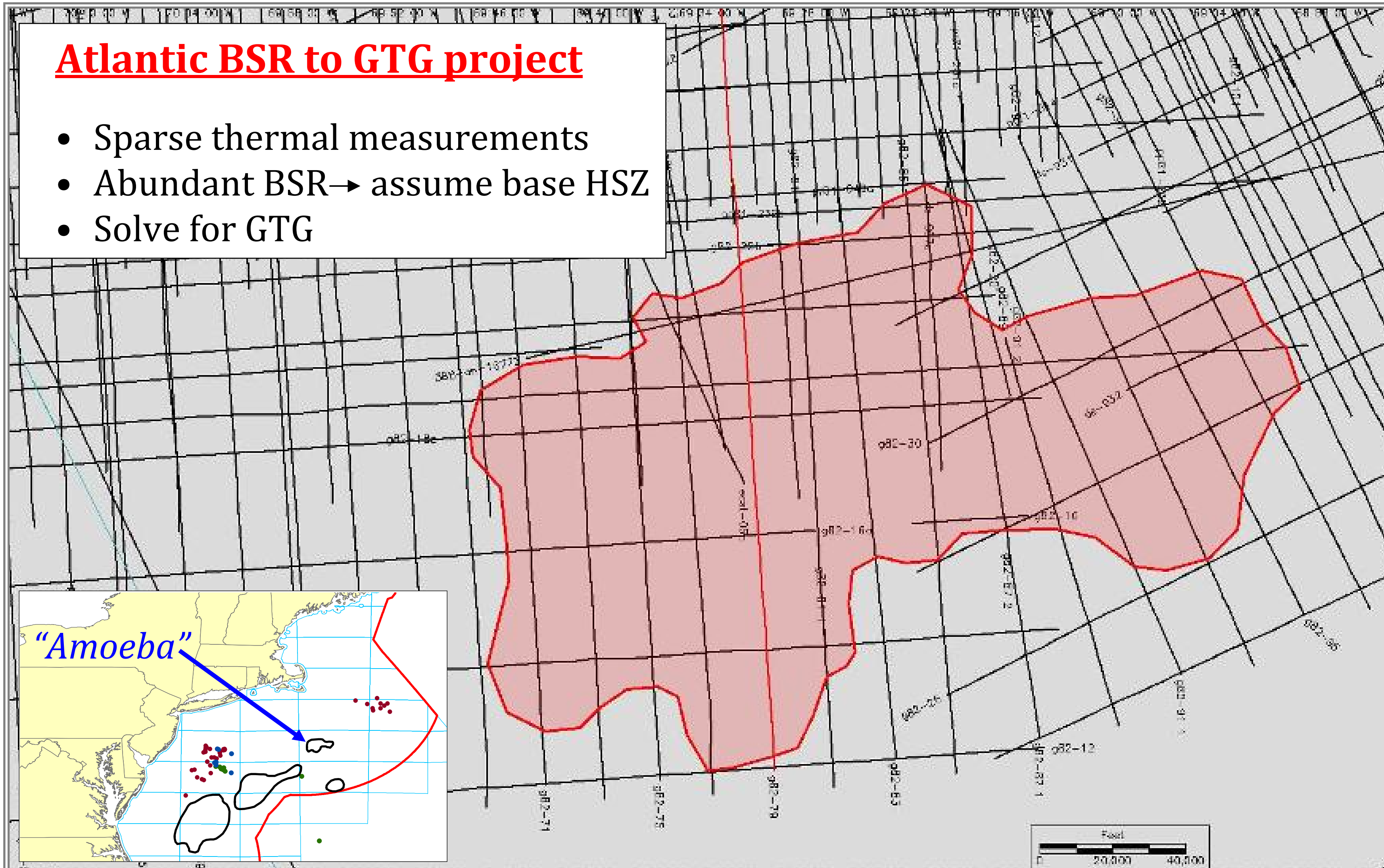

saturation
MattAtl2_combo_new Events
SAT_MEAN__
0.00537 - 0.02270
0.02271 - 0.04500
0.04501 - 0.06860
0.06861 - 0.08910
0.08911 - 0.10953
0.10954 - 0.13062
0.13063 - 0.15286
0.15287 - 0.18064
0.18065 - 0.23105
0.23106 - 0.33611

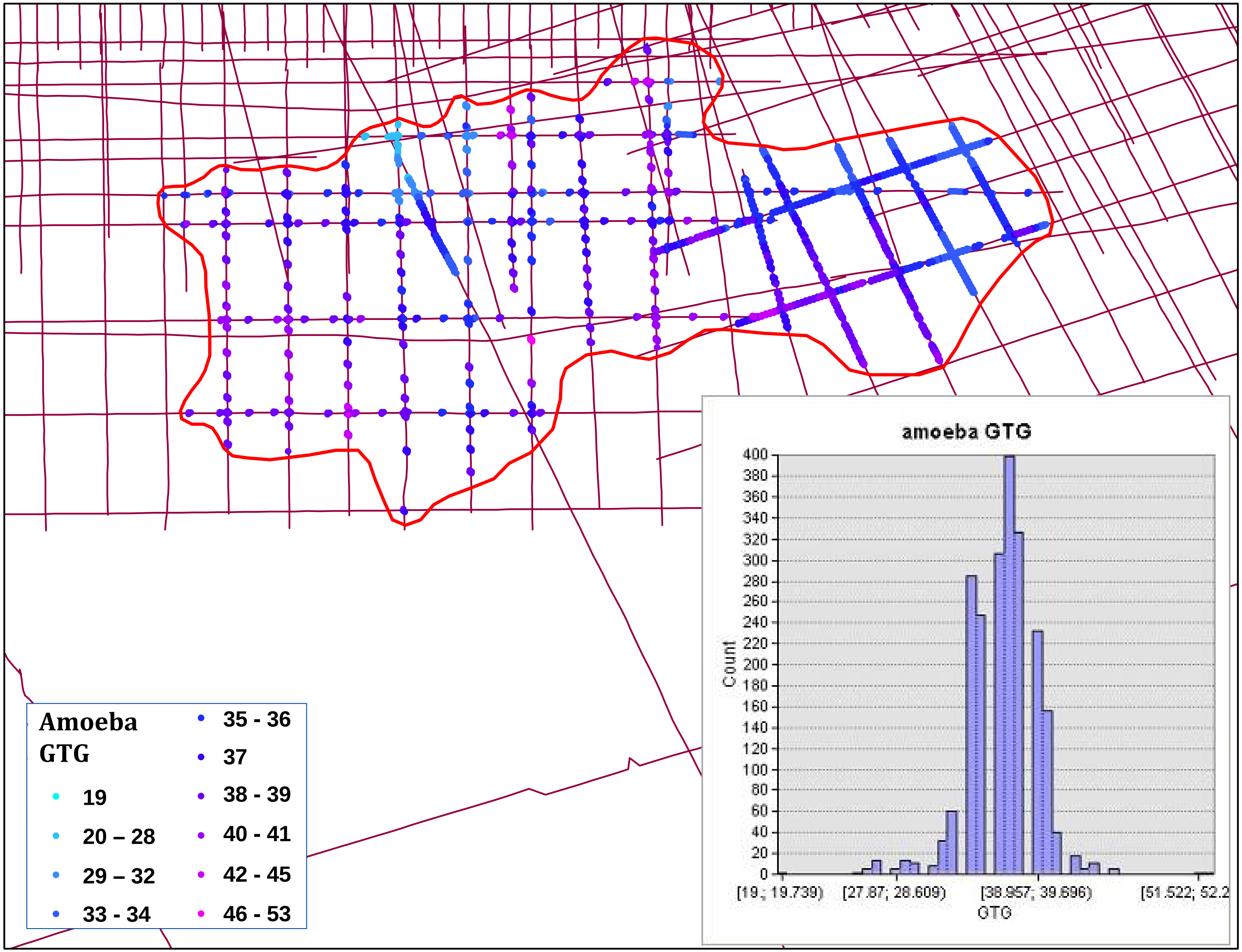

Bathymetry (m)
Atl3_modified Events
WD_
251 - 638
639 - 981
982 - 1475
1476 - 2089
2090 - 2576
2577 - 2964
2965 - 3335
3336 - 3721
3722 - 4089
4090 - 4482

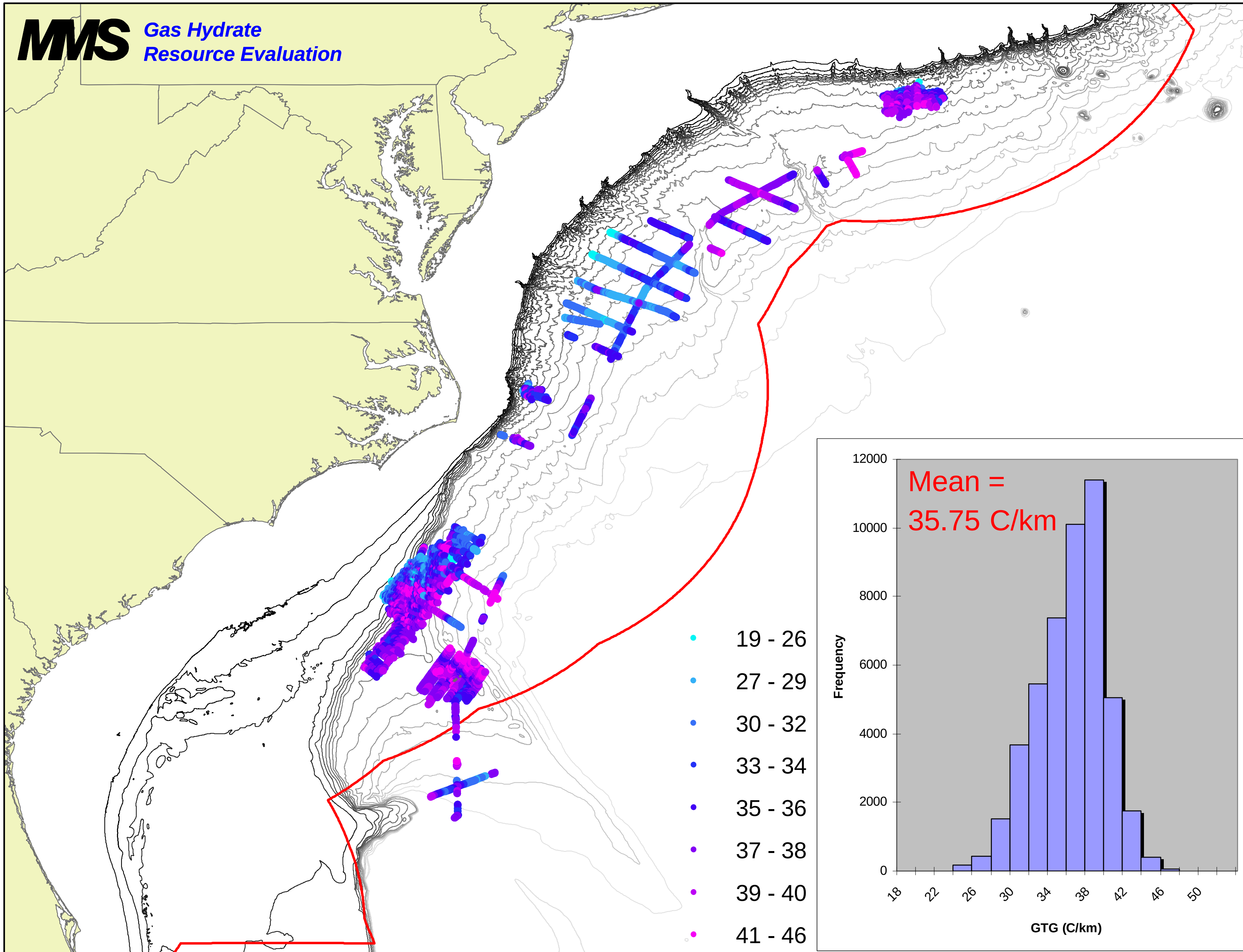

HSZ mean (m)
Atl3_modified Events
HSZ_MEAN__
1.6830 - 62.8803
62.8804 - 151.2255
151.2256 - 237.5883
237.5884 - 332.4639
332.4640 - 419.4675
419.4676 - 481.1832
481.1833 - 524.6393
524.6394 - 561.6809
561.6810 - 595.7494
595.7495 - 626.6533

Atlantic BSR to GTG project

- Sparse thermal measurements
- Abundant BSR→ assume base HSZ
- Solve for GTG



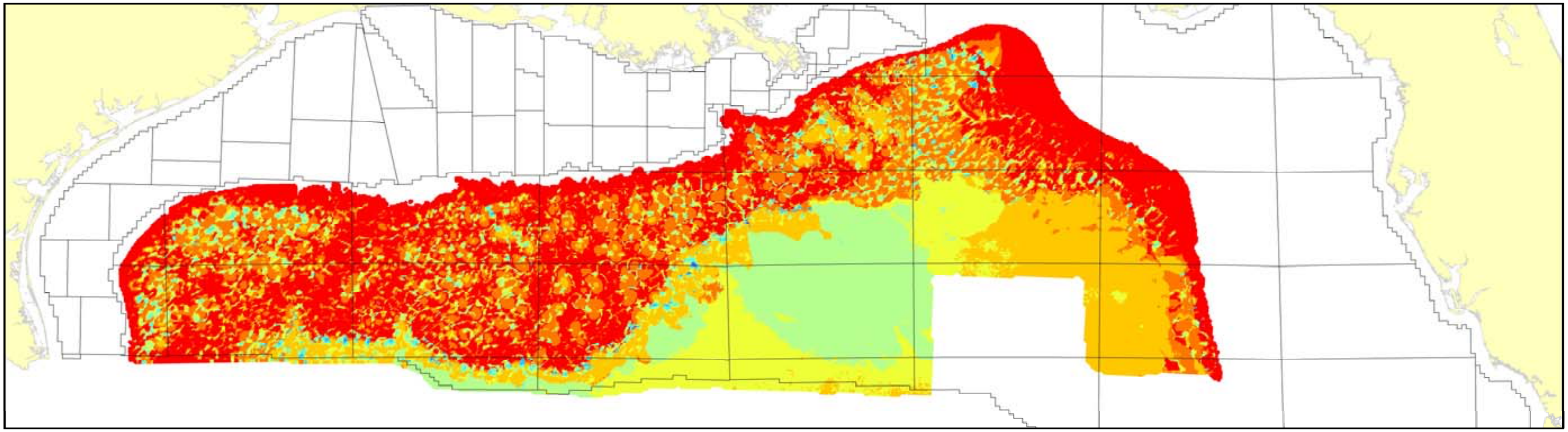

Amoeba GTG
19
20 – 28
29 – 32
33 - 34
35 - 36
37
38 - 39
40 - 41
42 - 45
46 - 53
amoeba GTG
Count
GTG
[19.; 19.739)
[27.87; 28.609)
[38.957; 39.696)
[51.522; 52.2



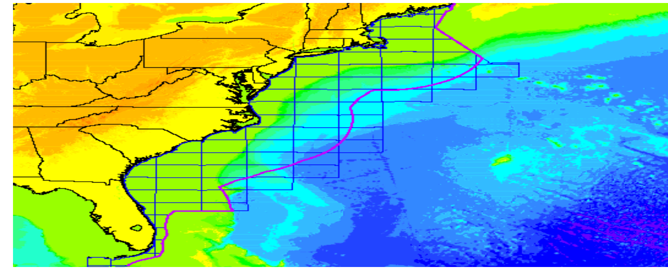
MMS
Gas Hydrate
Resource Evaluation
19 - 26
27 - 29
30 - 32
33 - 34
35 - 36
37 - 38
39 - 40
41 - 46
Mean =
35.75 C/km
Frequency
GTG (C/km)

Conclusions – GOM:

- In-place results reflective of GOM geology & complex geometries
- Model methodology and structure provide high degree of spatial resolution
- Disaggregated mass balance approach allows for component modification as new data and information become available



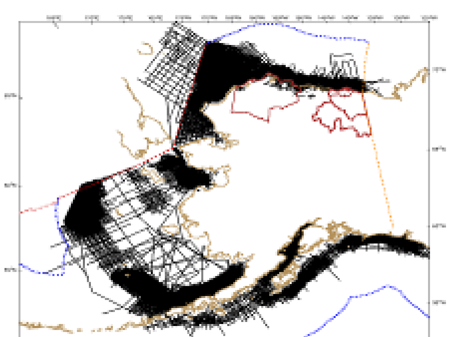
- Atlantic OCS underway - new challenges ahead:
  - → Generation/migration refinements
  - → Calibration to Blake Ridge volume estimates

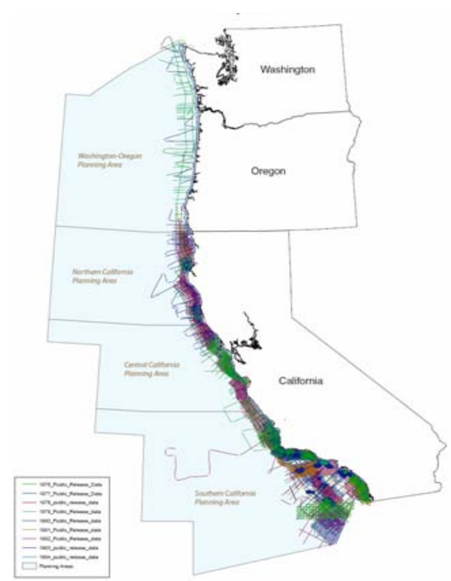


- Looking Ahead – Technically Recoverable resources
  - → Sand reservoirs only
  - → What recovery factor? Techniques?

Photo: Doyon Drilling, Inc.

- Looking Way Ahead:
  - → Pacific and Alaskan OCS
  - → Economically Recoverable



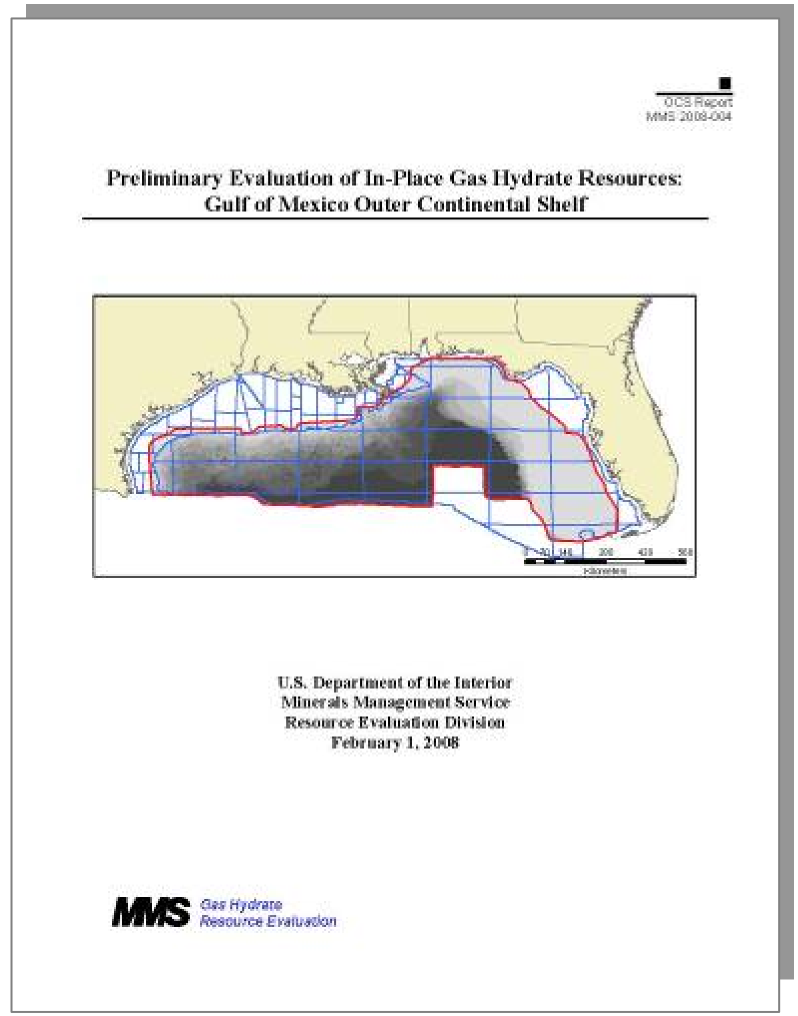


Complete GOM Report Available at:

http://www.mms.gov/revaldiv/GasHydrateAssessment.htm

Contact:

matt.frye@mms.gov


OCS Report
MMS 2008-004

Preliminary Evaluation of In-Place Gas Hydrate Resources:
Gulf of Mexico Outer Continental Shelf

U.S. Department of the Interior
Minerals Management Service
Resource Evaluation Division
February 1, 2008

MMS Gas Hydrate
Resource Evaluation

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