Gas Hydrate Resource Assessment

U.S. Outer Continental Shelf

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Independence Hub photo from Anadarko Petroleum Corp.

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BOEM manages the exploration and development of the nation's offshore resources. It seeks to appropriately balance economic development, energy independence, and environmental protection through oil and gas leases, renewable energy development and environmental reviews and studies.

- Total OCS = 7.1 million km^2
- ~ 15% natural gas, 27% oil

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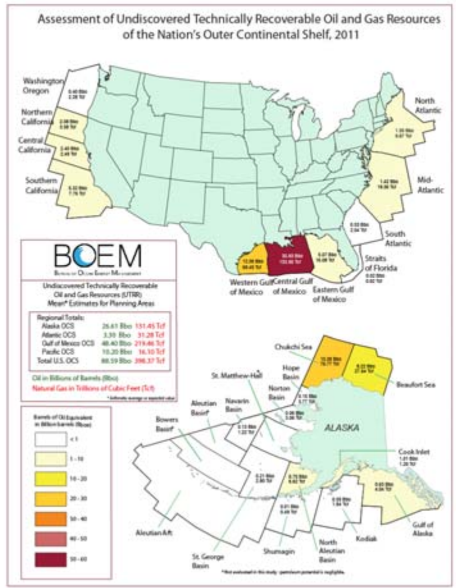
Resource Assessments: Conventional O&G v. Unconventional

Conventional Oil and Gas
(existing methods)
↓
Discovery Method
Subjective Method
↓
Limited Spatial Resolution

Unconventional Gas Hydrate
↓
(No Existing Methodology)
↓
Mass Balance Method
↓
Significant Spatial Component



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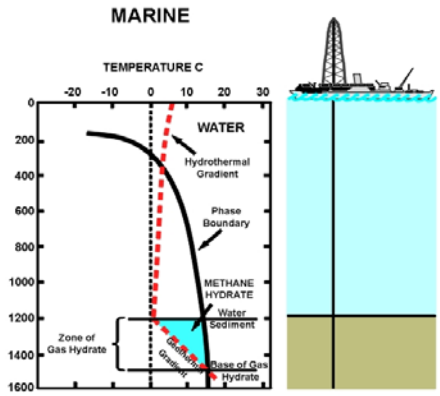
What is Gas Hydrate?

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 1000 m thick in GOM)



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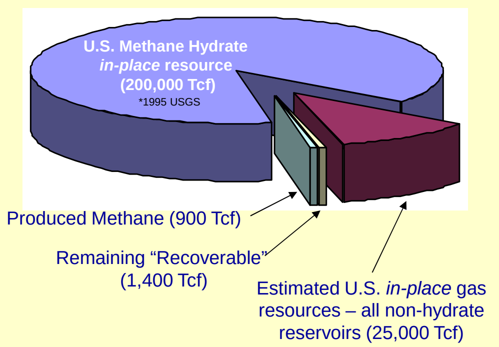
Why Are We Interested ?

Why are we interested in Gas Hydrate?

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

• Potentially recoverable energy resource !!!

Gas Resources



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Gas Hydrate Model Description

Model Specifications

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

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

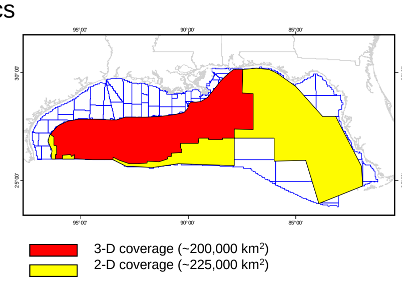
•**Inputs** – combination of spatial and empirical data

•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 Study Area – Gulf of Mexico

•Multi-channel seismic data (2D and 3D)
•Wellbore data (Industry & science wells)
•Modeled rates, functions, etc.



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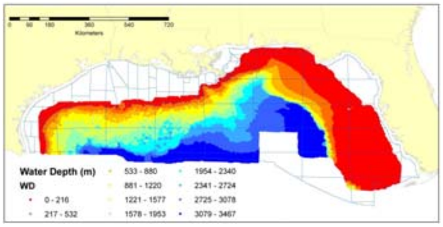
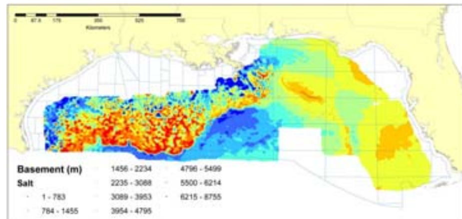
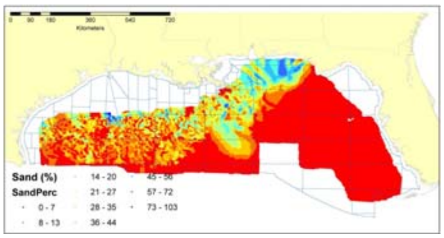
Spatial Inputs to Model



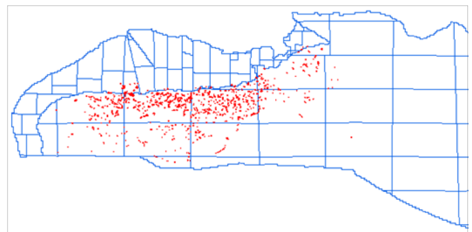
Water Depth



Mobile Salt / Basement morphology



Sand Distribution



Seafloor Anomalies

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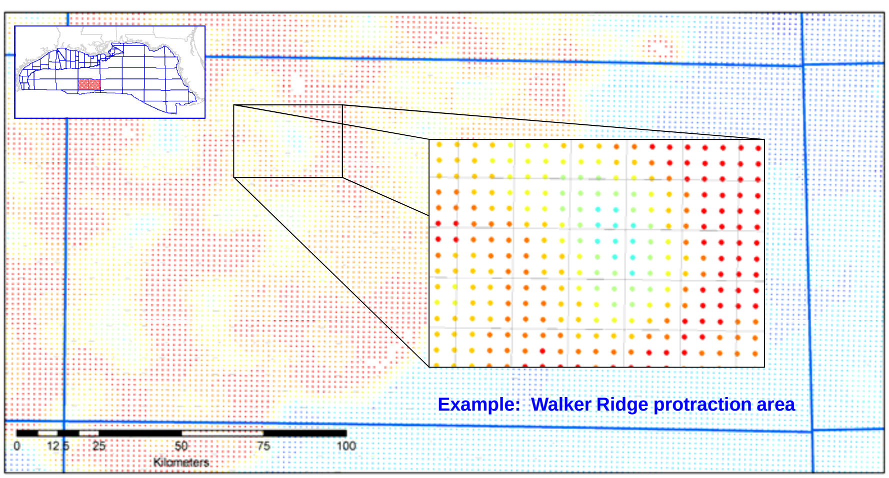
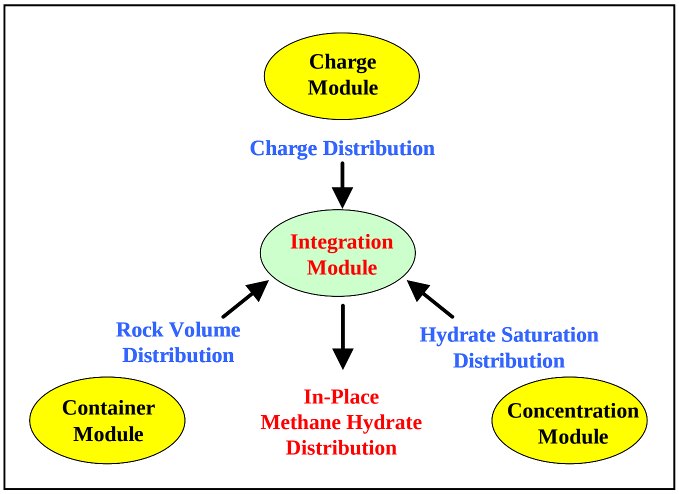
Model Cell Structure – Gulf of Mexico

- GOM study area ~ **450,000 km²**
- **202,079** model cells - each cell **2.32 km²** (5000' x 5000')



Gas Hydrate Model Methodology

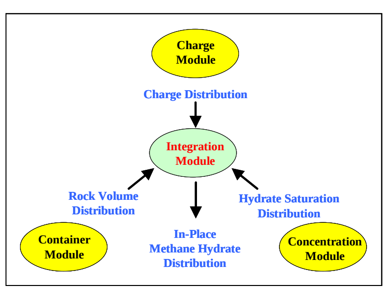


Charge Module

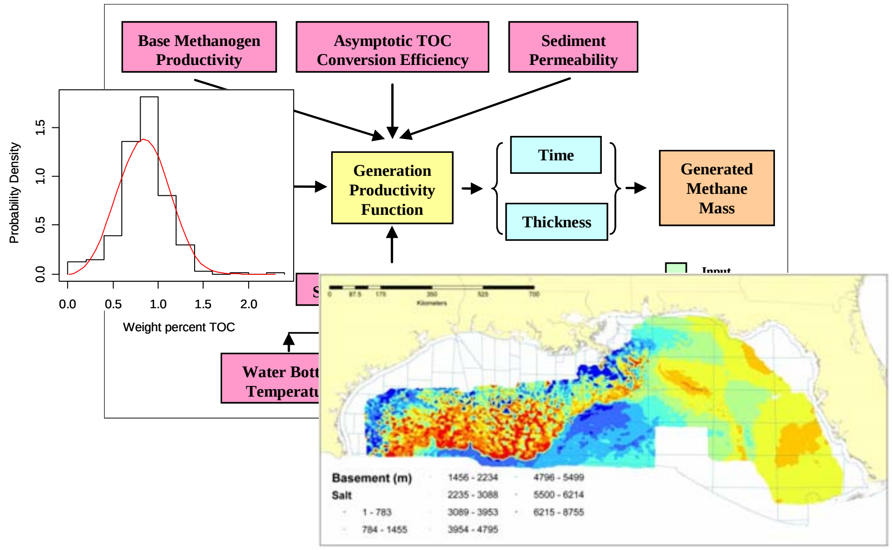
Charge Module

Generation Model

Migration Model

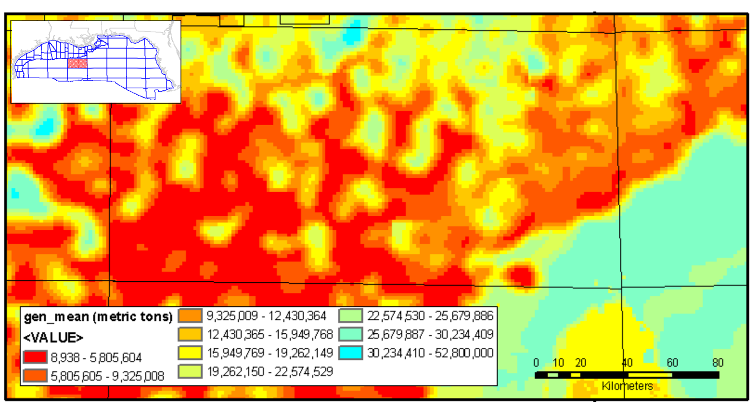


Generation Model



Generation Model Output

Charge: **Generation model** ⟶ Output

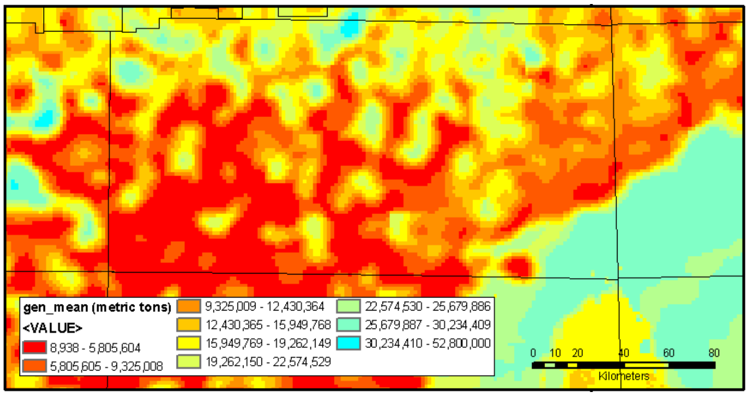


Migration Model

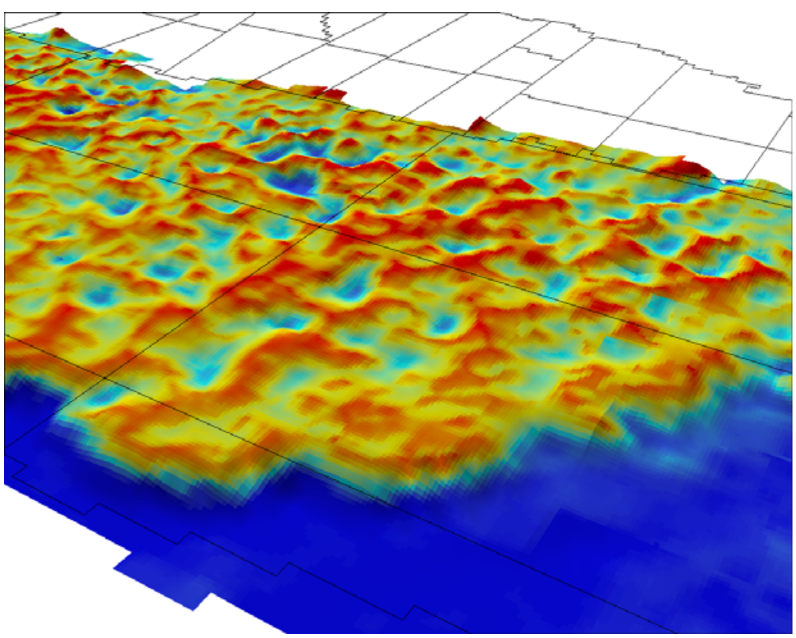
Charge: **Migration model** ⟶ *two end members*

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 of Salt spatial input



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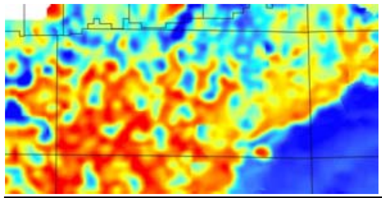
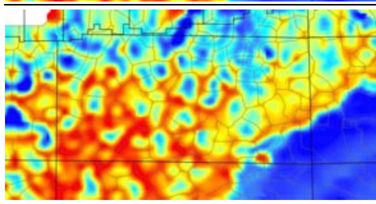
GIS Analysis



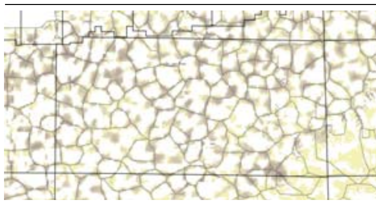
Top Salt structure map
↓
Flow Direction
↓
Basin

GIS Hydrologic Tools



Top Salt structure with Hydrodynamic catchments
↓
Curvature

GIS tool



Curvature map w/ catchments

White = negative curvature
Brown = positive curvature

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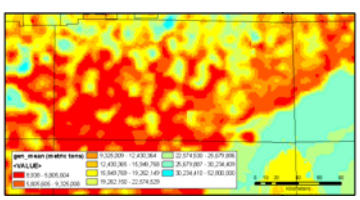
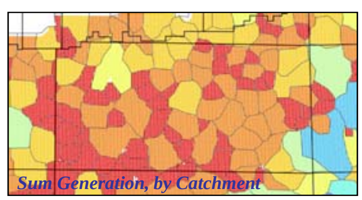
Dip-Driven Gas Migration

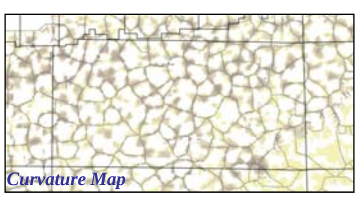
100% dip-driven migration continued…….

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

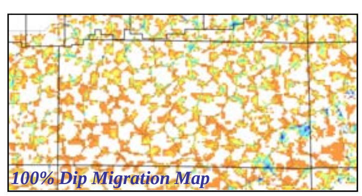




Sum Generation, by Catchment



Curvature Map



100% Dip Migration Map

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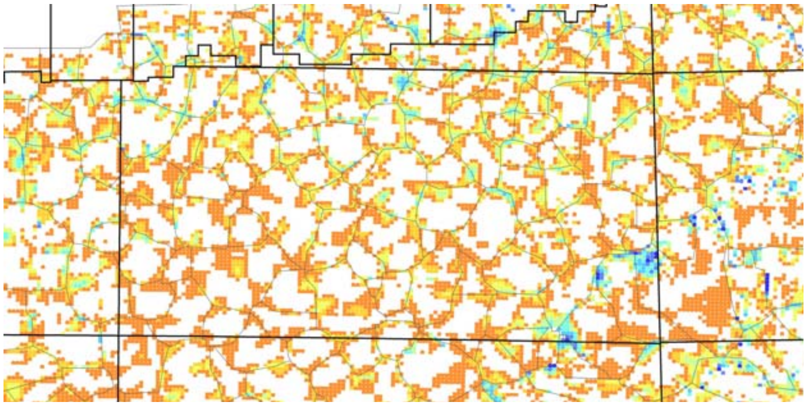
Dip-Driven Gas Migration

100% dip-driven migration continued…….

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



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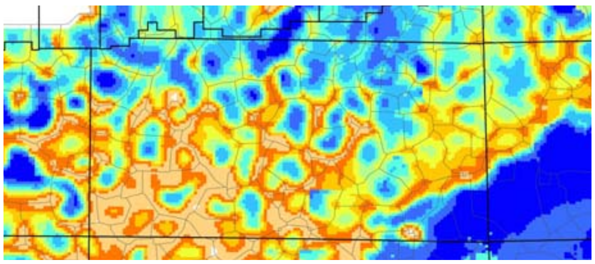
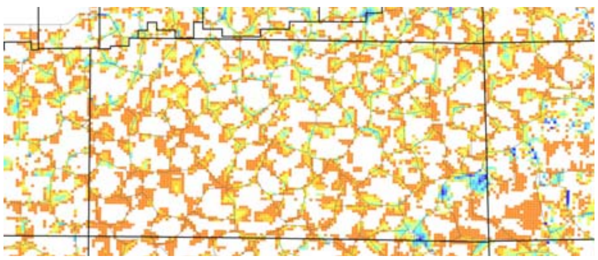
Migration Model

Which migration method is correct?



100% Vertical

Gas remains in cell of origin



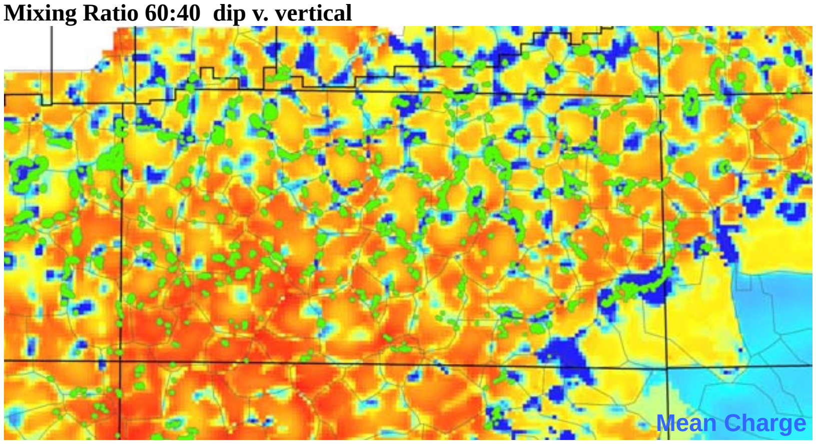
100% Dip Driven

Gas migrates to margin of basins

Migration model

Based on sensitivity analysis using known seafloor seeps…….

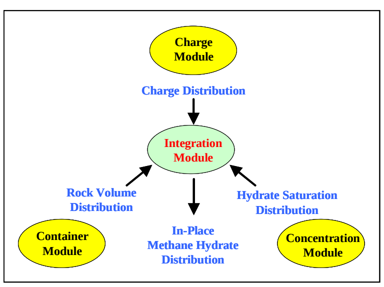
Mixing Ratio 60:40 dip v. vertical



Container module

Container Module

Gross HSZ - UZ = Net HSZ



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Container Module

Stability Equation (from Milkov and Sassen, 2001)

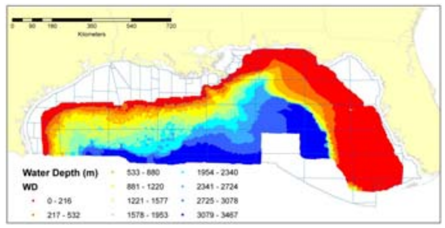
$$f(B) = -(-9.6 \times \ln(B) + 88.4) \times C/1000 - 295.1 \times B^{-0.6} + 8.9 \times \ln(C + B) - 50.1$$

geothermal gradient — water bottom temperature — phase stability expression

sediment temperature expression

where,

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



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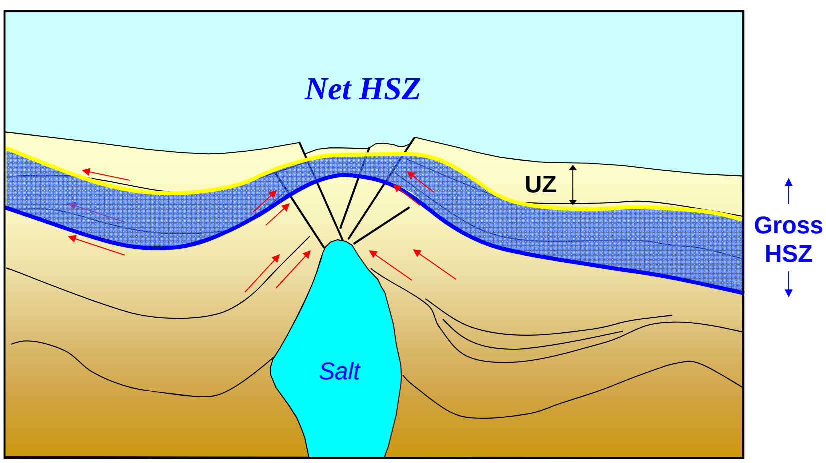
Container Module

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

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



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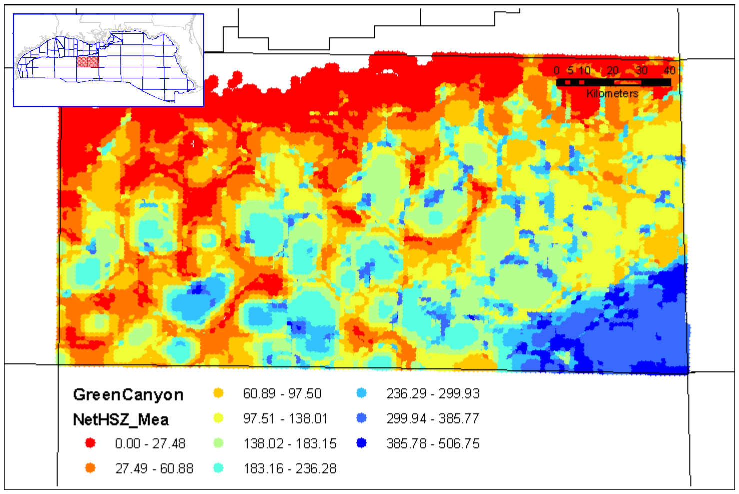
Container Module

Net HSZ (= Gross HSZ – UZ)



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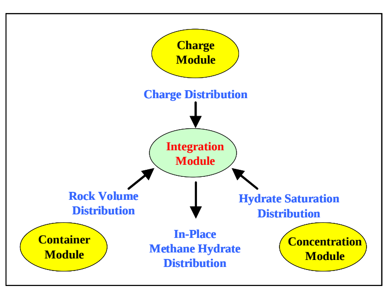
Concentration Module

Concentration Module

HSZ porosity, by lithologic facies

↓

Pore space saturated by gas hydrate



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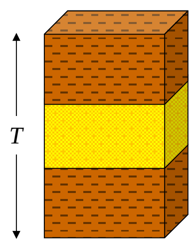
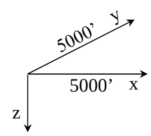
Concentration Module

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

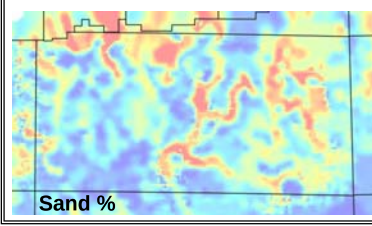
Shale Void = (Volume)(Porosity)
Volume Shale = (x)(y)[(*T*)(1-sand%)]
Porosity Shale = *f*(*d*)





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

From input file:
sand %



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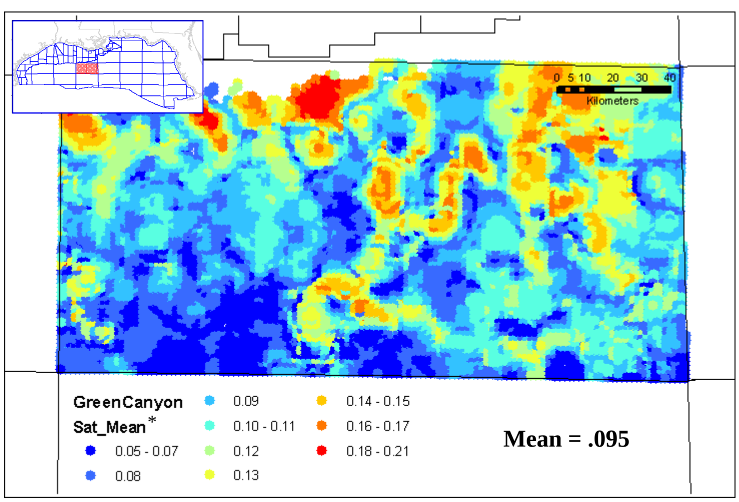
Concentration Module

Concentration

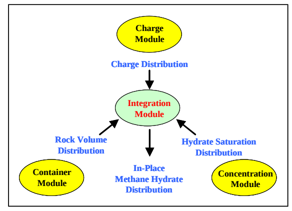


*decimal % of the bulk rock volume

Integration Module

Integration Module

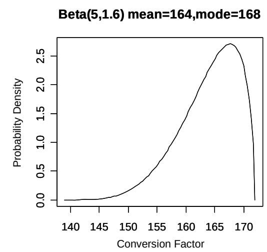
For each model cell, we:



•Compare charge to available container ⟶ retain smaller of two

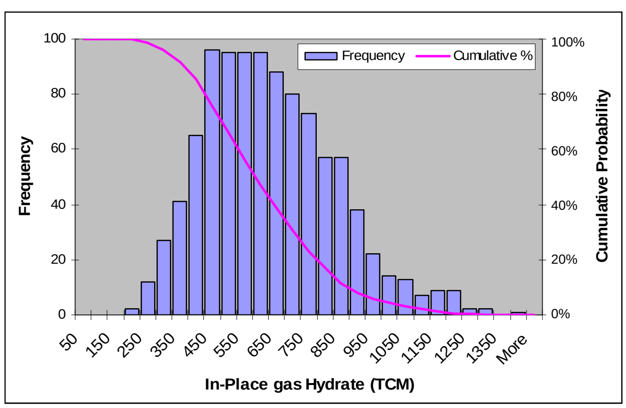
•*Except* at surficial anomalies ⟶ manually fill if undercharged

•Convert from RTP to STP:



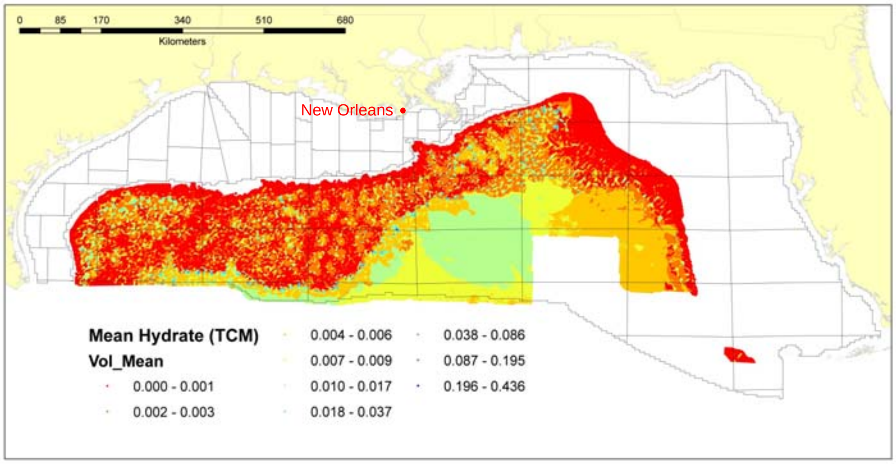
Assessment Results - Graphical

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



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

Assessment Results - Spatial



- In Place resource estimate – not necessarily technically/economically recoverable
- No introduction of geologic risk – petroleum system success on all trials

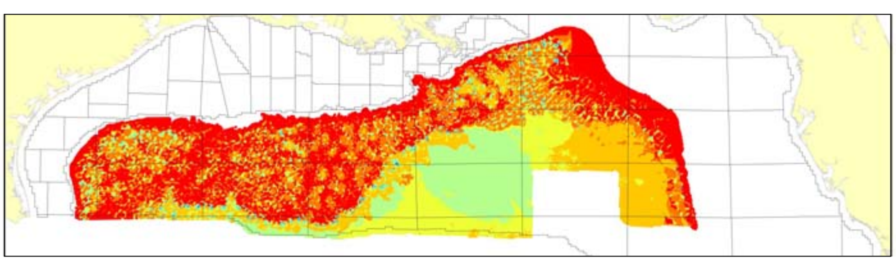
Summary

<u>Conclusions - GOM:</u>

•Resource assessment methodology different than typical O&G assessments
⟶ Spatial rather than strictly empirical

•Advanced GIS tools used to model gas generation and migration
⟶ *Flow Direction, Basin, Curvature*

•Approach applicable to other O&G basins around the world with proper modifications to account for local subsurface geometries and data availability



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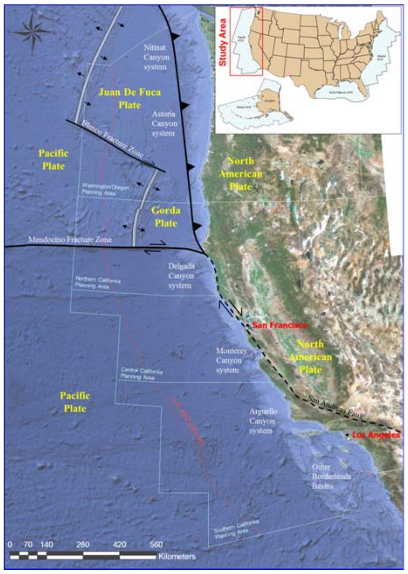
Pacific OCS



Pacific Outer Continental Shelf

- Complex tectonics (subduction, spreading, wrench)
- Several point source sediment systems
- Near-shore basins
- Relatively thin sediment cover in places
- Paucity of seismic data

Model Changes

- 100% vertical gas migration
- Crust age & BSR incorporated
- Mixed spatial/empirical inputs
- HSZ constrained by sediment thickness

*Official results release expected 3Q 2012

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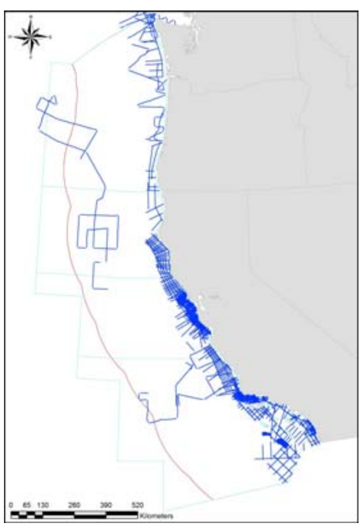
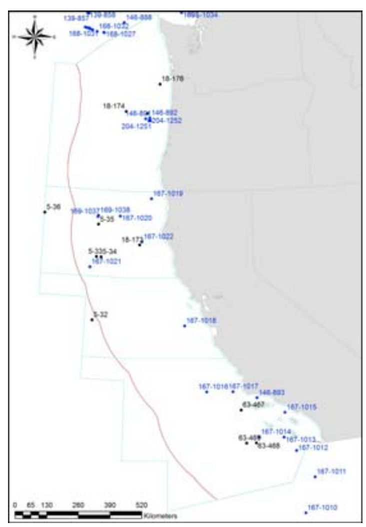
Pacific OCS – Spatial Inputs



2D Seismic Data



DSDP/ODP wells

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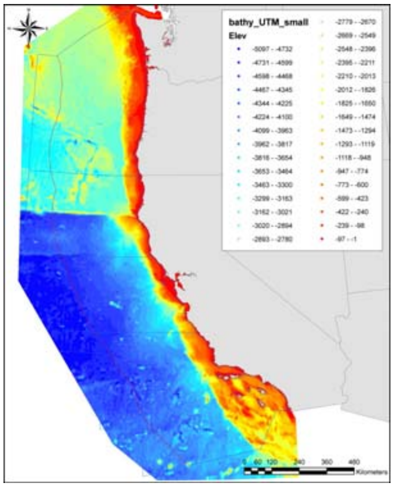
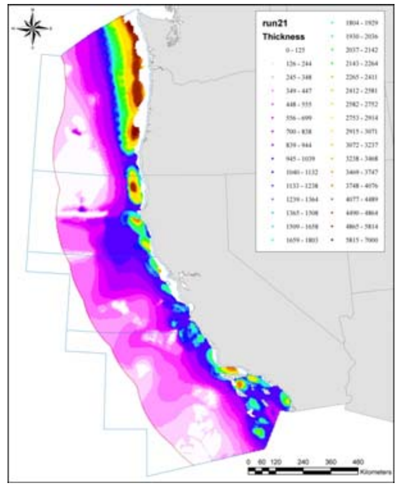
Pacific OCS – Spatial Inputs



Water Depth



Sediment Thickness

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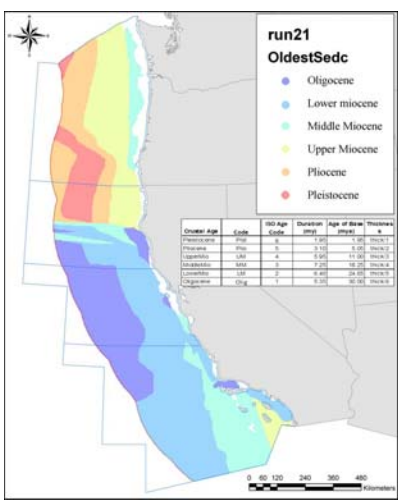
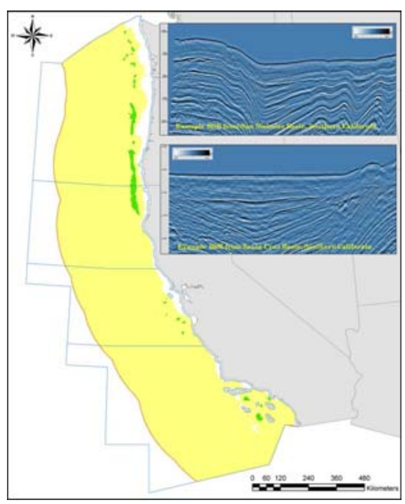
Pacific OCS – Spatial Inputs



Crust Age



Bottom Simulating Reflectors (BSR)

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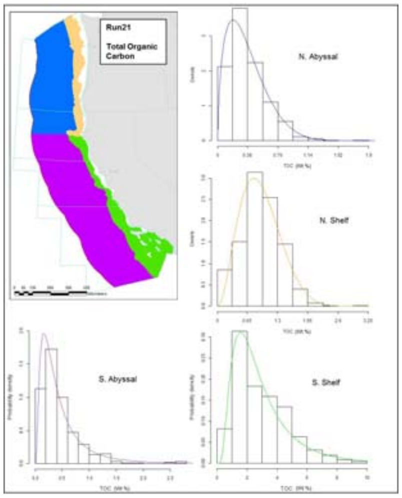
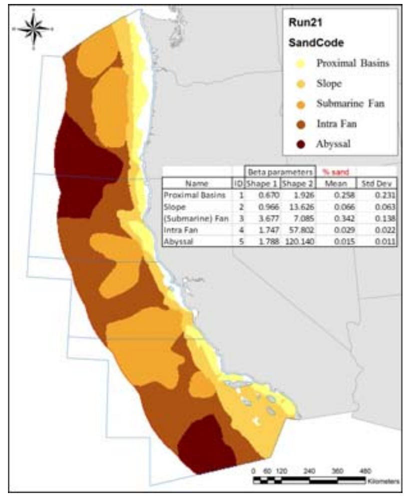
Pacific OCS – (partial) Spatial Inputs



Total Organic Carbon



Sand Distribution

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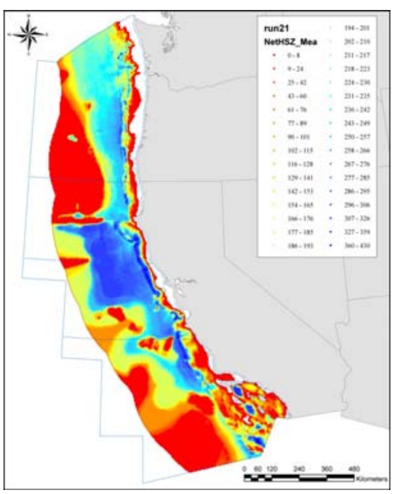
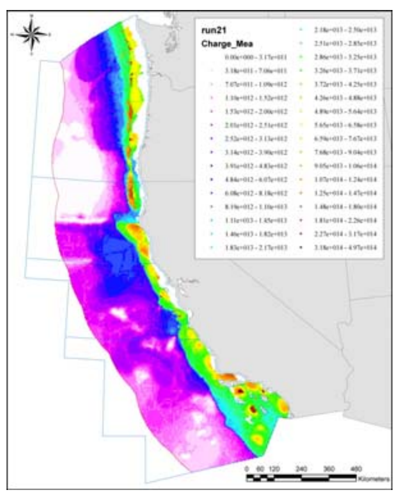
Pacific OCS - Outputs



Hydrate Stability Zone (HSZ)



Gas Charge

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In Place Gas Hydrate Volume