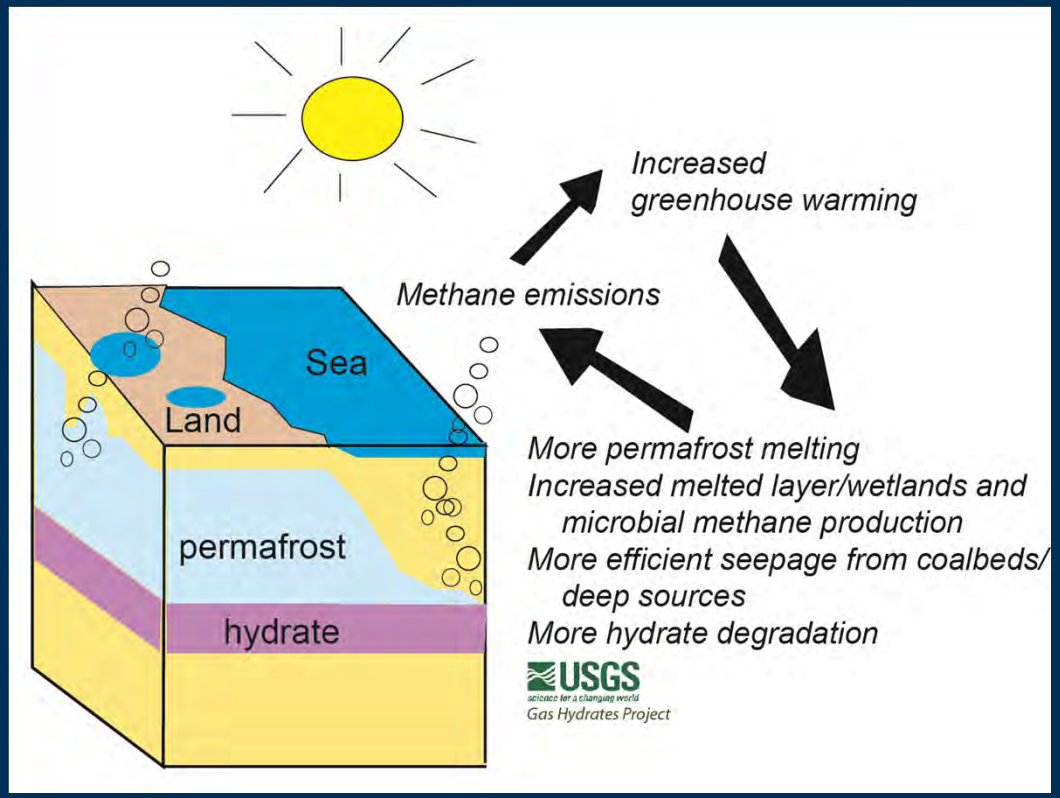
Quantifying Climate-Hydrate Interactions: A Progress Report



Carolyn Ruppel
USGS Gas Hydrates Project

Approved for release by the USGS 3/14

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Motivation: Top-Down and Bottom-Up Methane Budgets Disagree

- +87 Tg/yr disparity in emissions from “other” natural sources (~6 Tg/yr attributed to hydrates)
- +76 Tg/yr disparity in total atmospheric chemical sink

What is the true role of gas hydrate dissociation?

How could gas hydrate contributions be discerned?

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Kirschke et al., Nature Geoscience, 2013

The “Arctic Methane Catastrophe” Hypothesis—Example of Top-Down/Bottom-Up Conflict

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-- Continued warming may destabilize methane trapped in gas hydrate deposits
-- Methane flux increasing to 50 Tg per year
-- Based on observations on Siberian margin

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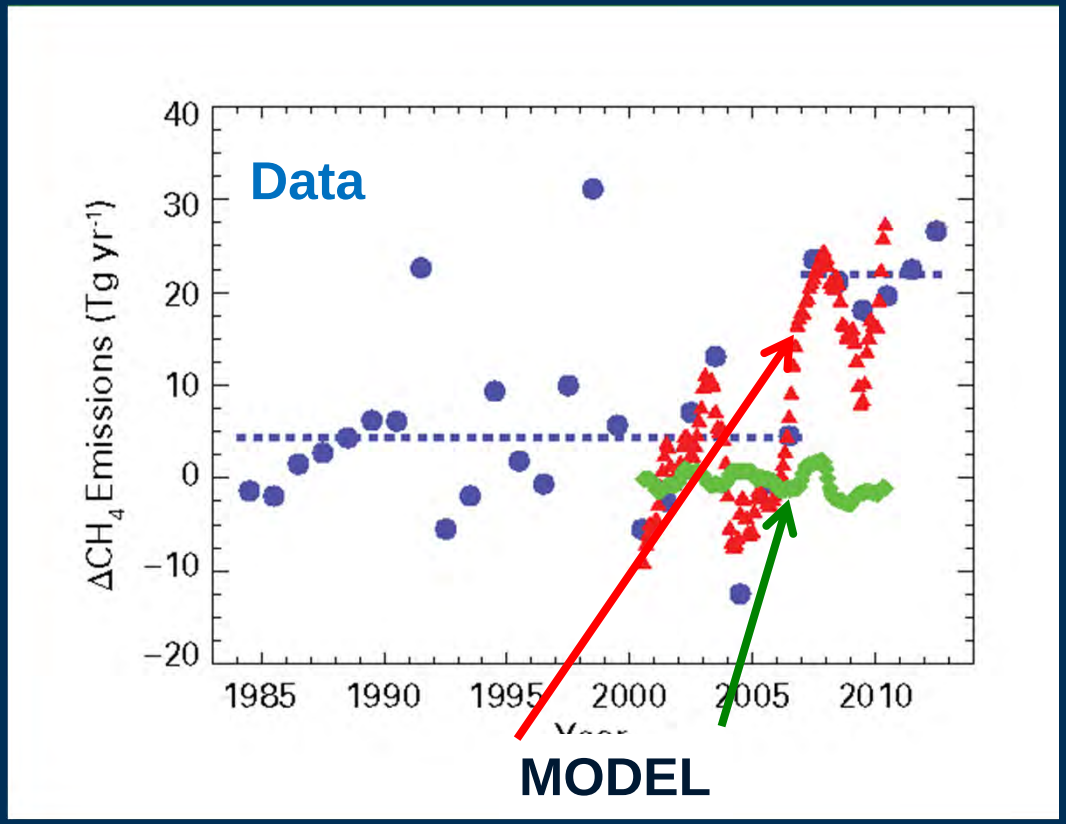
Shakhova et al., 2010

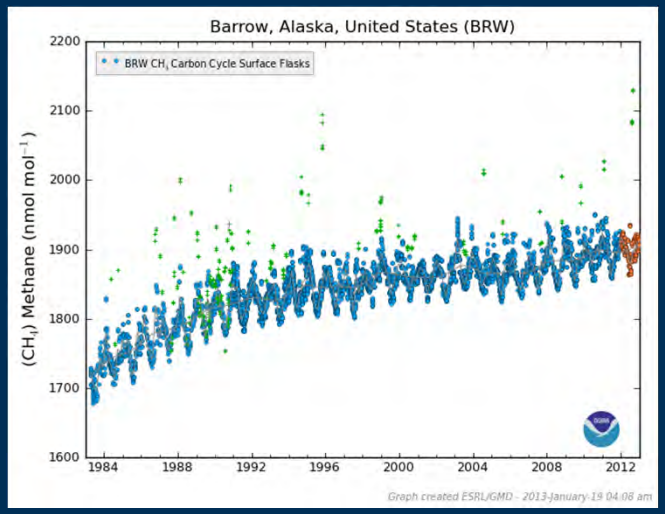
Top-Down: No discernible signal from increased Arctic methane emissions



"*Analysis of the data indicates that tropical and mid-latitude Northern Hemisphere emissions have contributed to increases in atmospheric CH_4 since 2007, and that there has not yet been a measurable increase in Arctic CH_4 emissions.*"

WMO GHG report, Nov. 2013

Barrow, AK record



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Chronology

Spring 2008: DOE/USGS workshop to focus efforts on climate-hydrates research

Fall 2008: First round of DOE funding for climate projects

2009: *EU program PERGAMON launched*

2009: NRL-led cruise in Beaufort Sea

2010: DOE PI meeting in Atlanta—reporting of first climate-hydrate project results

Publication of East Siberian margin results

2011: DOE/USGS workshop to prioritize climate-hydrates issues

2012: DOE funds more climate projects

2013: DOE funds several more climate projects

EU program PERGAMON ends

Norwegian Centre of Excellence launched (UiT)

US interagency discussions about future of climate work

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Geographic Locations of Climate-Hydrate Studies

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In several locations, researchers have suggested climate-hydrate connections without supporting evidence

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1. Impact of Climate Change on Gas Hydrates

Climate warming

Sea level rise

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upper ocean (700 m) warming

Ruppel, *Nature Knowledge*, 2011

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2. Contributions to Atmospheric Methane from Gas Hydrate Dissociation

Only settings where methane originates at <100 m water depth contribute methane directly to the atmosphere

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DOE Project: Fate of water column methane, MIT-UNH-USGS

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MODEL APPROACH: Climate, Ocean Circulation, and Other

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Data about hydrates and methane emissions are sparse, so model inputs are poorly constrained

Some models ignore sinks or critical processes

Archer et al., 2008

Change in radiative forcing

Isaksen et al., 2012

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Biastoch et al., 2011

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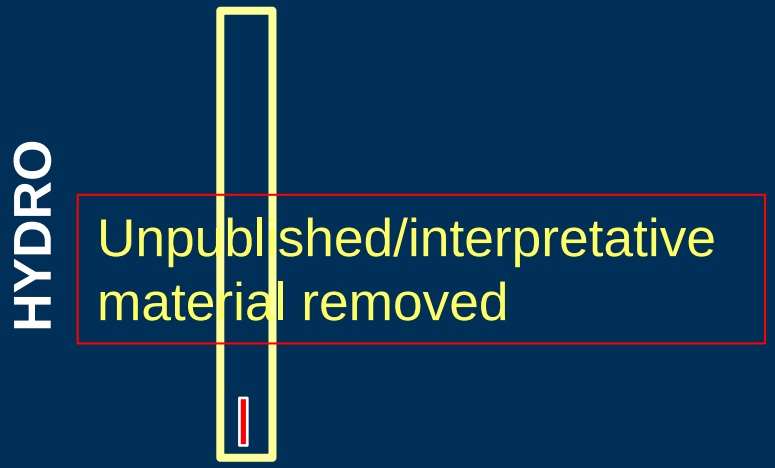
DATA APPROACH: Multidisciplinary quantification of sources and sinks (sediments/water column/atmosphere)



Methane sources
Methane concentration

↑ ***Methane flux***

Methane production

Methane oxidation

Dissolved methane/methane bubbles

↑***Methane flux***

Methane sink (AOM)
Methane production
Amount of hydrate and gas

Key challenge: Distinguishing methane released by gas hydrate from other methane (e.g., noble gas fingerprinting?)

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Climate Susceptible Gas Hydrate Deposits

global

Arctic

Permafrost too thick; hydrate too deep

Deep ocean temperatures very stable

USGS

Ruppel, *Nature Knowledge*, 2011

“Relict” Gas Hydrate Associated with Subsea Permafrost on Arctic Continental Shelves (< 120 m water depth)

- Arctic shelves subjected to significant warming (up to 15ºC or more) over the course of the Holocene due to sea level rise
- Methane released at seafloor reaches the atmosphere

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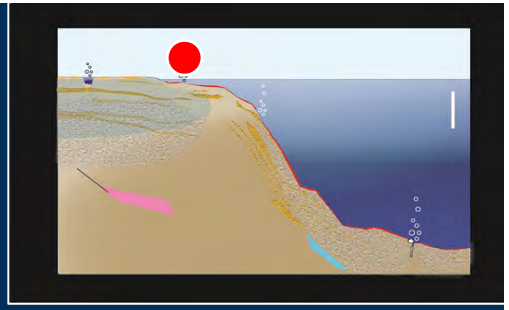
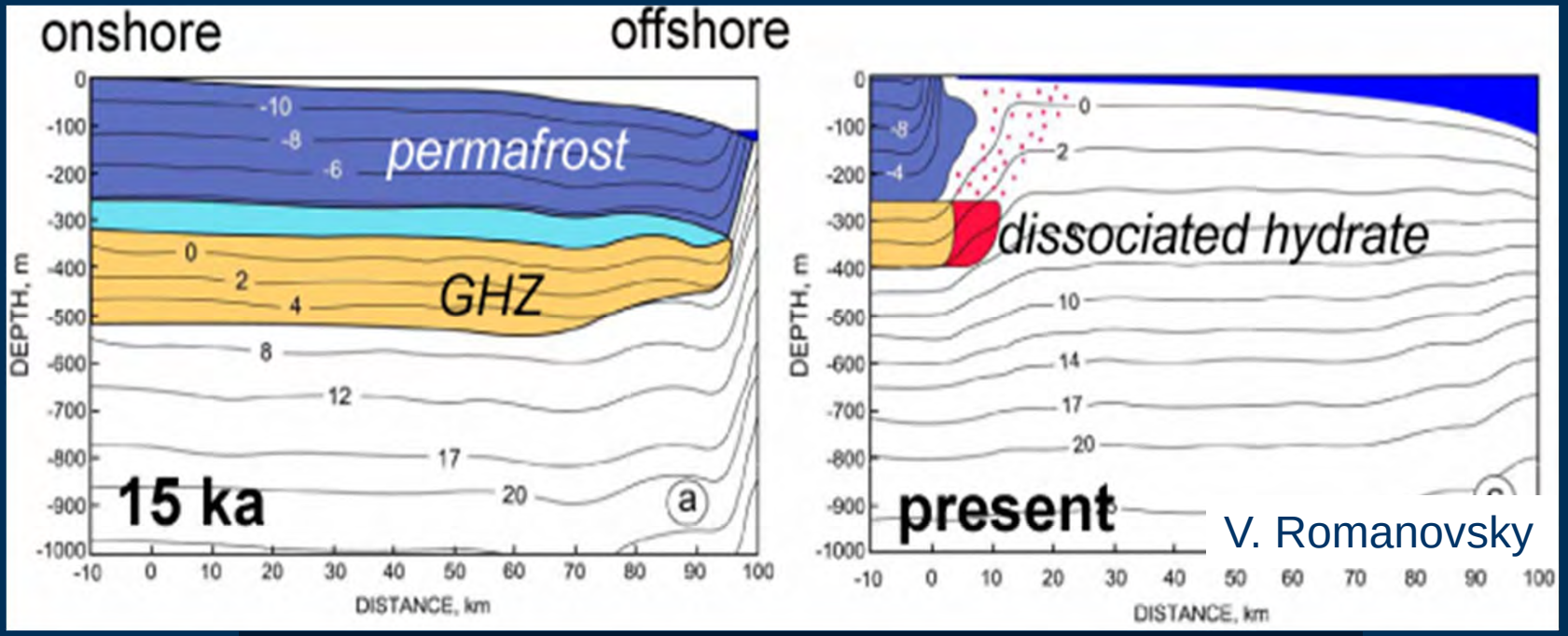
Shallow Circum-Arctic Ocean Continental Shelves





100 yr after inundation, gas hydrate (if it exists) at the top of the stability zone starts to dissociate

After 3000 yr, permafrost has thawed and gas hydrate (if it exists) is dissociating at the top and bottom of the stability zone

Ruppel, 2011

USGS

Permafrost-Associated Gas Hydrate is Not Widespread

Methane hydrate is stable deeper than ~225 m in permafrost (shallower if higher order HC) and to depths of several hundred meters below the base of permafrost

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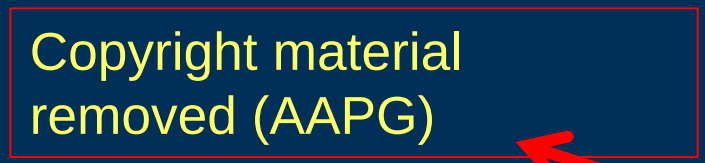
Ruppel, 2007

USGS

Why are methane flux predictions so high?

Researchers assume too much subsea permafrost and too much hydrate



Offshore (subsea) permafrost assumed to extend to 100 m isobath (corresponding to Late Pleistocene lowstand)

Collett et al., 2011

USGS

Kara Sea Subsea Permafrost extends only to ~20 m isobath

Subsea permafrost and relict hydrate not as extensive as previously thought on some margins

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US-Canada Beaufort Sea Permafrost

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Refraction data

Permafrost limit

Portnov et al., 2013

ALASKA

CANADA

DOE Summer 2014/2015:
Controlled source EM for subsea permafrost imaging (SIO/USGS)

USGS

Brothers et al., 2012

120 m isobath
Permafrost refractions

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Hammerhead

Brothers et al., 2012

Copyright material removed (AAPG)

Collett et al., 2011

Example: Offshore Permafrost and Hydrate in US Beaufort

- Subsea permafrost extends nowhere >30 km offshore, nor beyond the 20 m isobath
- Best and only evidence for relict hydrate near Hammerhead (Shell drill site)
- Has the permafrost degraded (along with hydrate) or was it never there?
- Accepted IODP pre-proposal for drilling

Gas Hydrates on Upper Continental Slopes (275 – 550 m)

- Feather edge of gas hydrate stability (theoretically 0 thickness)
- Small contemporary perturbations (warming) in bottom water temperature can lead to dramatic dissociation
- Methane does not reach the atmosphere

DOE Projects:
Cascadia,
Svalbard,
Beaufort Sea

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Svalbard Margin Upper Continental Slope

Widespread seeps active since at least 4 ka near upper edge of deepwater hydrate stability

Recent seepage events related to ocean temperature changes?

Methane over the site is from northern European wetlands, not the seeps

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Westbrook et al., 2009

Unpublished non-USGS material removed

seeps

DOE Summer 2014: Water column project, OSU; Flux project, USGS

1 km

Skarke et al., in review

US Atlantic Margin Seeps

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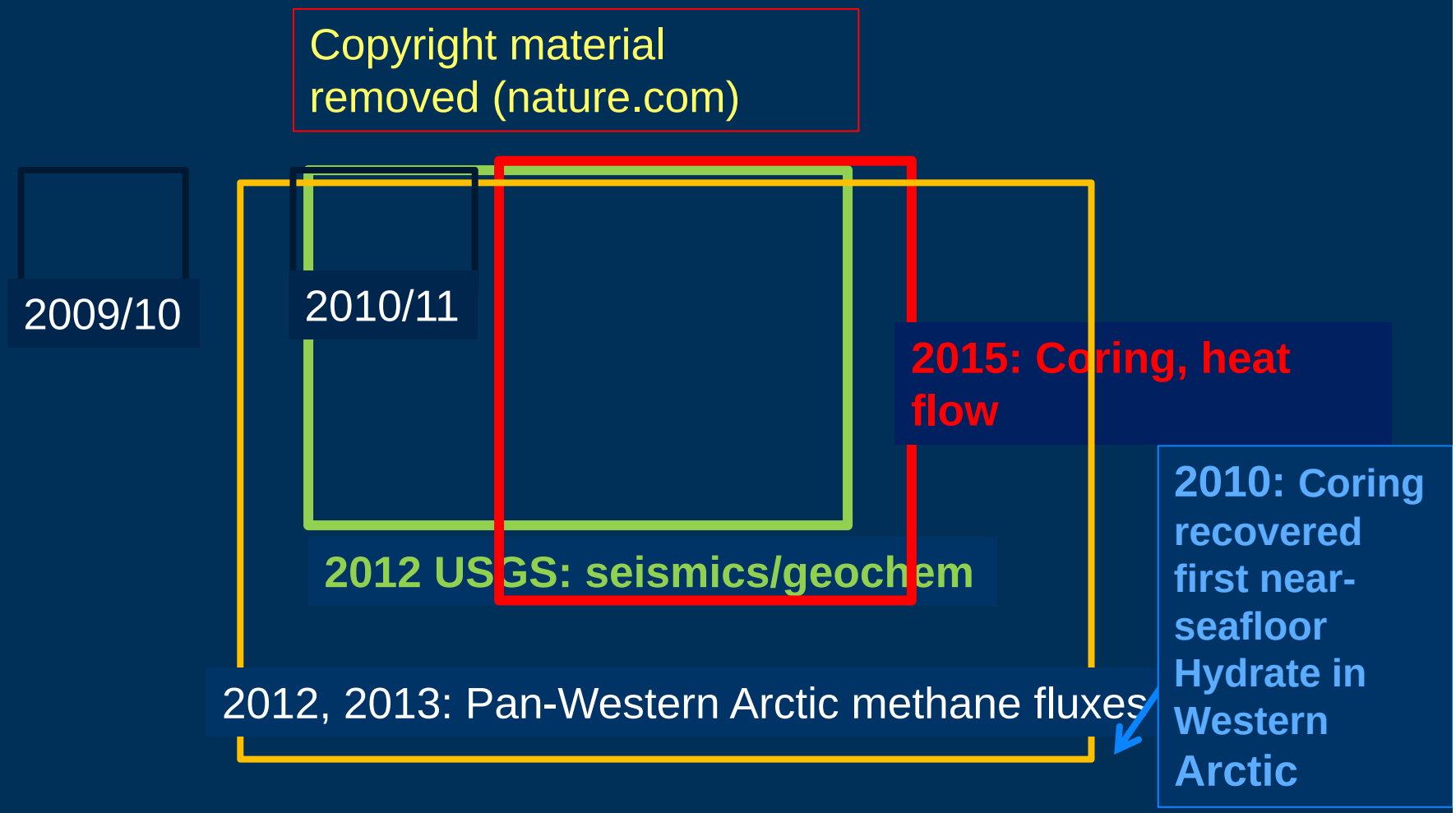
Brothers et al., 2013

Beaufort Sea Upper Continental Slope Research



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Ruppel, *Nature Knowledge*, 2011

Beaufort Margin Hydrate System

Hydrates cover a minimum 40,000 km^2 area

BSR (base of gas hydrate) recognized in 80% of area with water depth 400 to 2800 m

Classic location for hydrate-slope failure association

2010 deepwater hydrate

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USGS

Upper Slope Methane Concentrations/Sink Strength

Methane elevated near seafloor on upper slope

Top hydrate

METHANE

No methane plumes yet found with multibeam water column backscatter

Unpublished/interpretive material removed

Top hydrate

OXIDATION

USGS

3D Thermal Modeling

Observed base of gas hydrate is consistently too deep

Documented long term intermediate ocean warming

Estimated amount of upper slope hydrate poised to break down

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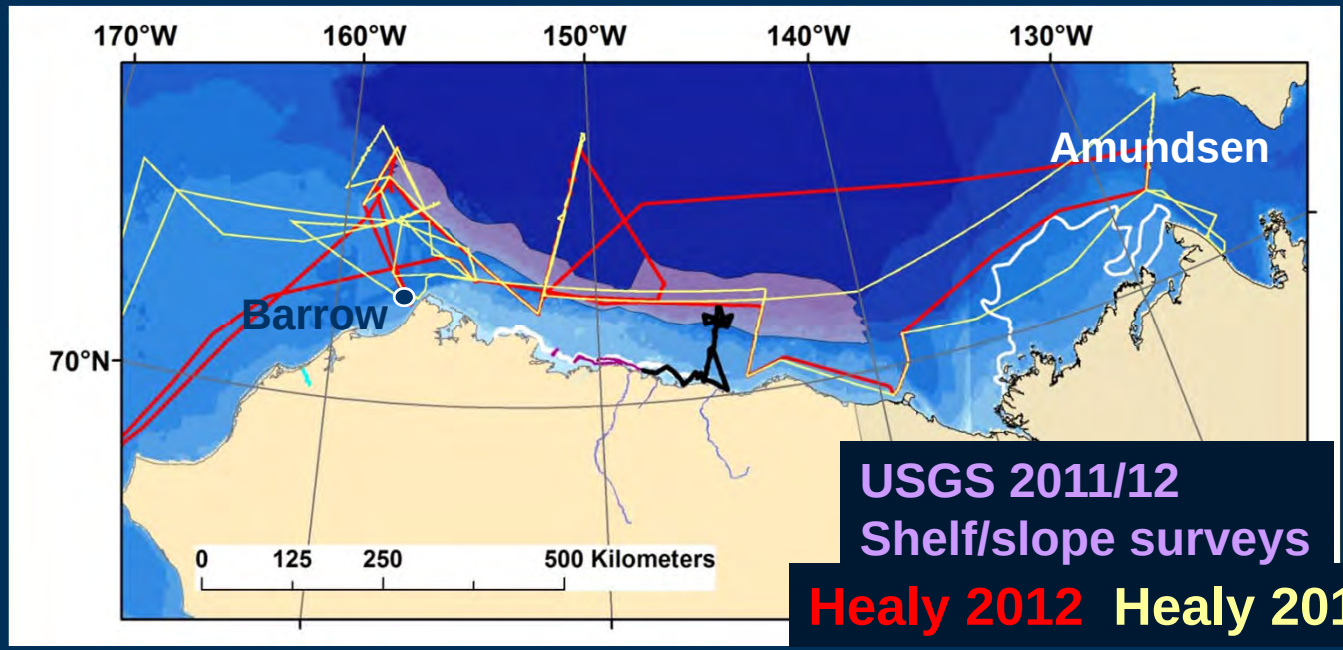
Phrampus et al., in review

Pan-Western Arctic Methane Fluxes: ~6000 km of USGS surveys on shelf, slope, and deepwater from Bering Strait to Amundsen Gulf, 2011-2013

Atmospheric marine boundary layer (MBL) measurements

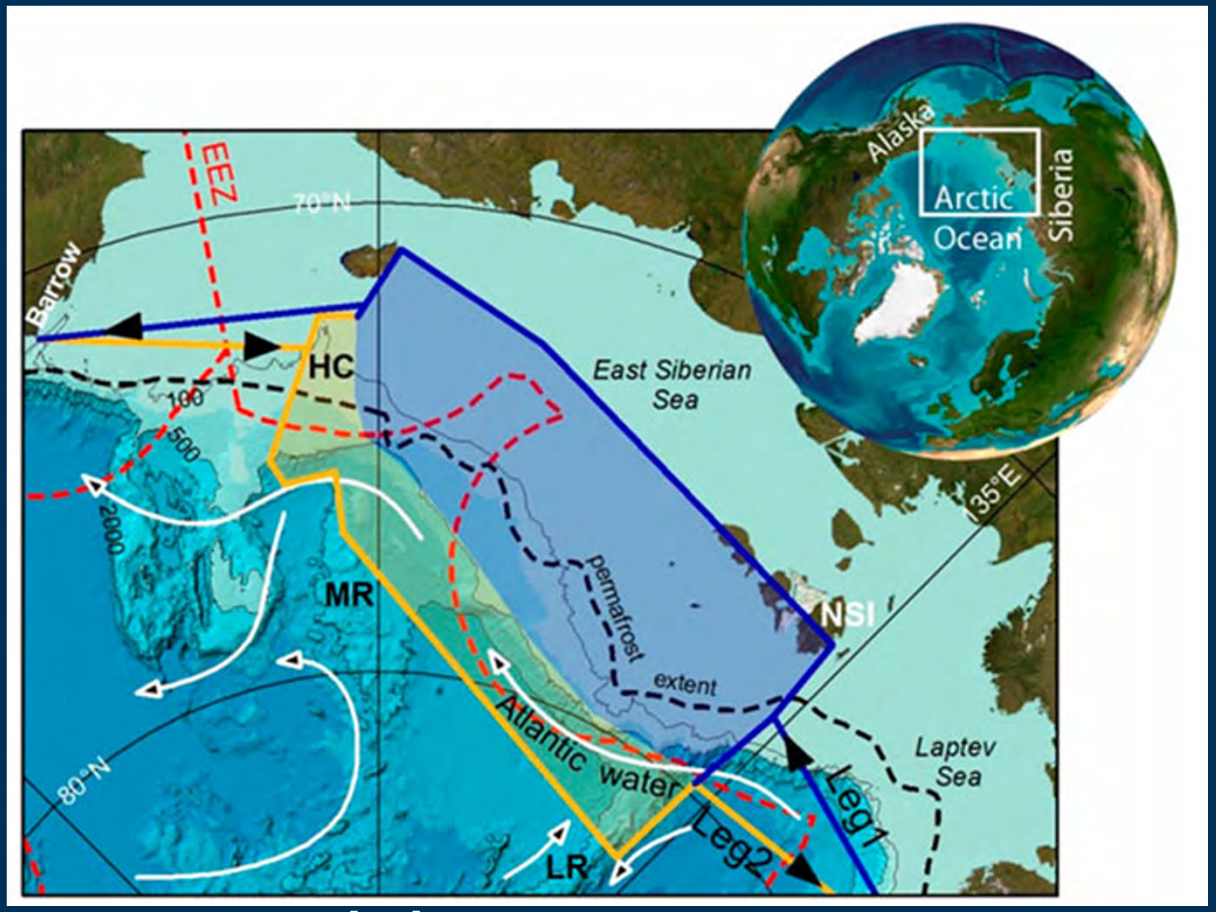


USGS 2011/12
Shelf/slope surveys

Healy 2012 Healy 2013

USGS

2014 SWERUS (Oden) Pan-Eastern Arctic expedition



SWERUS website

Will acquire flux measurements, cores, and other data across upper slope and shelf edge from Sweden to Barrow

Flux measurements should be complementary to USGS data in Western Arctic

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Copyright material removed (Science)

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Comparison: Ocean-Atmospheric Methane Fluxes (Disparate Techniques)

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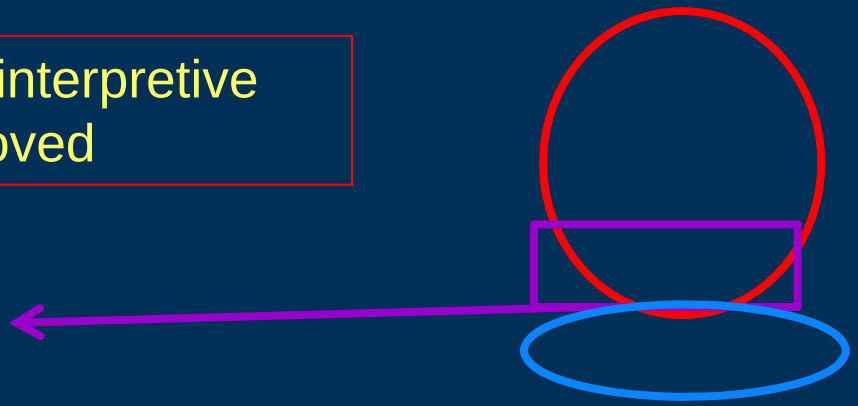

Recent paper doubled this

Summary

Substantial contrast between top-down and bottom-up estimates of atmospheric methane sources/sinks; hydrates play a role in this disparity

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