The National Academies of

SCIENCES · ENGINEERING · MEDICINE

Oil in the Sea IV:
Inputs, Fates, and Effects

Committee Meeting 7

March 11, 2021

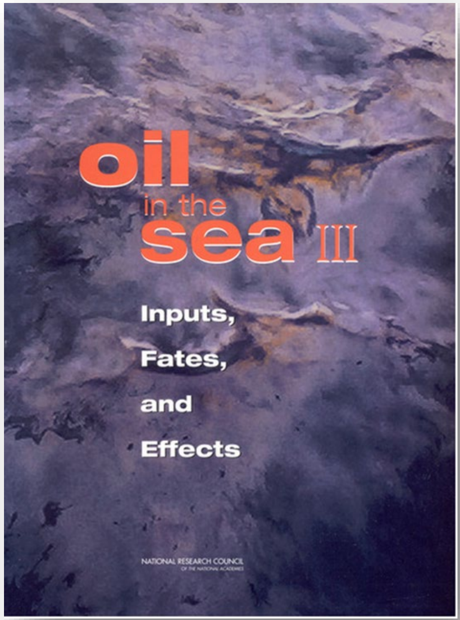
We will start at 11:30am EST

*This meeting will be recorded and posted on our project website

Photo Credit: NOAA

Welcome

- NASEM Consensus Study
- Update to Oil in the Sea III
- Sponsored by:
  - American Petroleum Institute
  - Bureau of Ocean Energy Management
  - Bureau of Safety and Environmental Enforcement
  - Fisheries and Oceans Canada
  - Gulf of Mexico Research Initiative
  - National Academies
- Information Gathering Session



Statement of Task

With regards to <u>inputs</u>:

1. Examine natural and anthropogenic sources of hydrocarbons entering the marine environment.
2. Develop quantitative estimates of hydrocarbon inputs to the marine environment.
3. Review progress in implementing the recommendations from the 2003 report
4. Provide recommendations to improve estimates of inputs and identify focus areas for reducing hydrocarbon inputs from human activities.

Statement of Task

With regards to fates and effects:

1. Assess and discuss the characteristics and behavior of hydrocarbons in the marine environment, the transport and fate in the marine environment, and the effects on marine life and ecosystems.
2. Characterize the risk posed to the marine environment.
3. Review progress in implementing the recommendations from the 2003 report regarding fates and effects.
4. Provide recommendations to improve understanding of the fates and effects of hydrocarbons on the ecosystem.

Committee Membership

- Kirsi Tikka (Chair)
- Ed Levine (Vice-chair)
- Akua Asa-Awaku
- C.J. Beegle-Krause
- Victoria Broje
- Steve Buschang
- Dagmar Etkin-Schmidt
- John Farrington
- Julia Foght
- Bernie Goldstein
- Carys Mitchelmore
- Nancy Rabalais
- Jeff Short
- Scott Socolofsky
- Berrin Tansel
- Helen White
- Michael Ziccardi

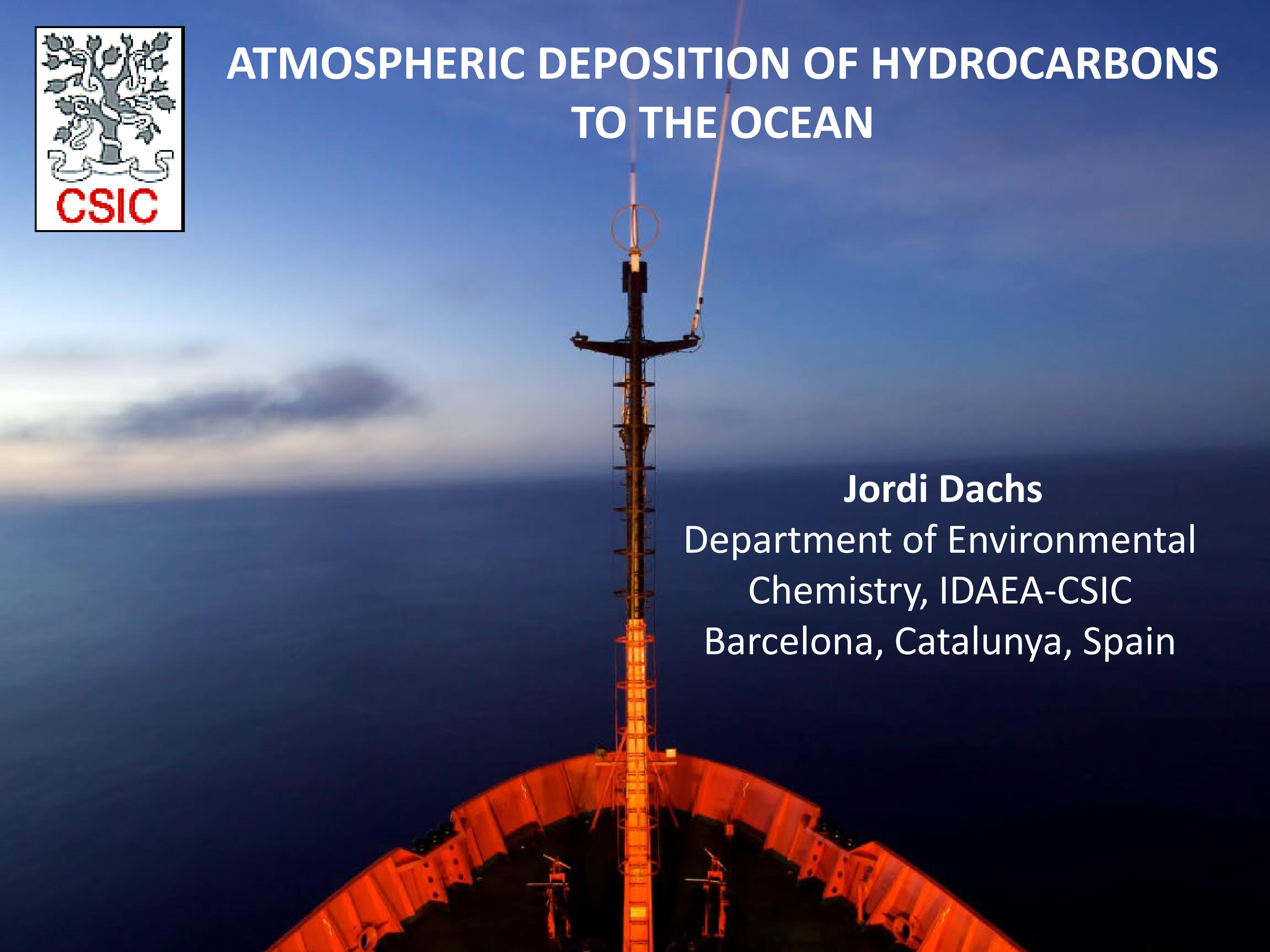
Agenda

11:30am	Welcome
11:40am	Inputs: Atmospheric Deposition
12:20pm	Natural Resource Damage Assessments: successes and challenges
1:00pm	BREAK
1:30pm	Oil and Gas Landscape Offshore Mexico
2:30pm	*Deepwater Horizon* Oil Spill – Inputs, Fates, and Effects
3:45pm	*Adjourn*

Zooming Guidance

- Please keep your line muted unless talking
- Please keep your video off unless you are talking
- Please raise your virtual hand if you want to comment or ask a question. The chat box will also be open.
- For those logged in to the webinar, use the Q&A function to submit questions or comments
- This meeting is being recorded. Recording will be posted in roughly a week's time

ATMOSPHERIC DEPOSITION OF HYDROCARBONS TO THE OCEAN

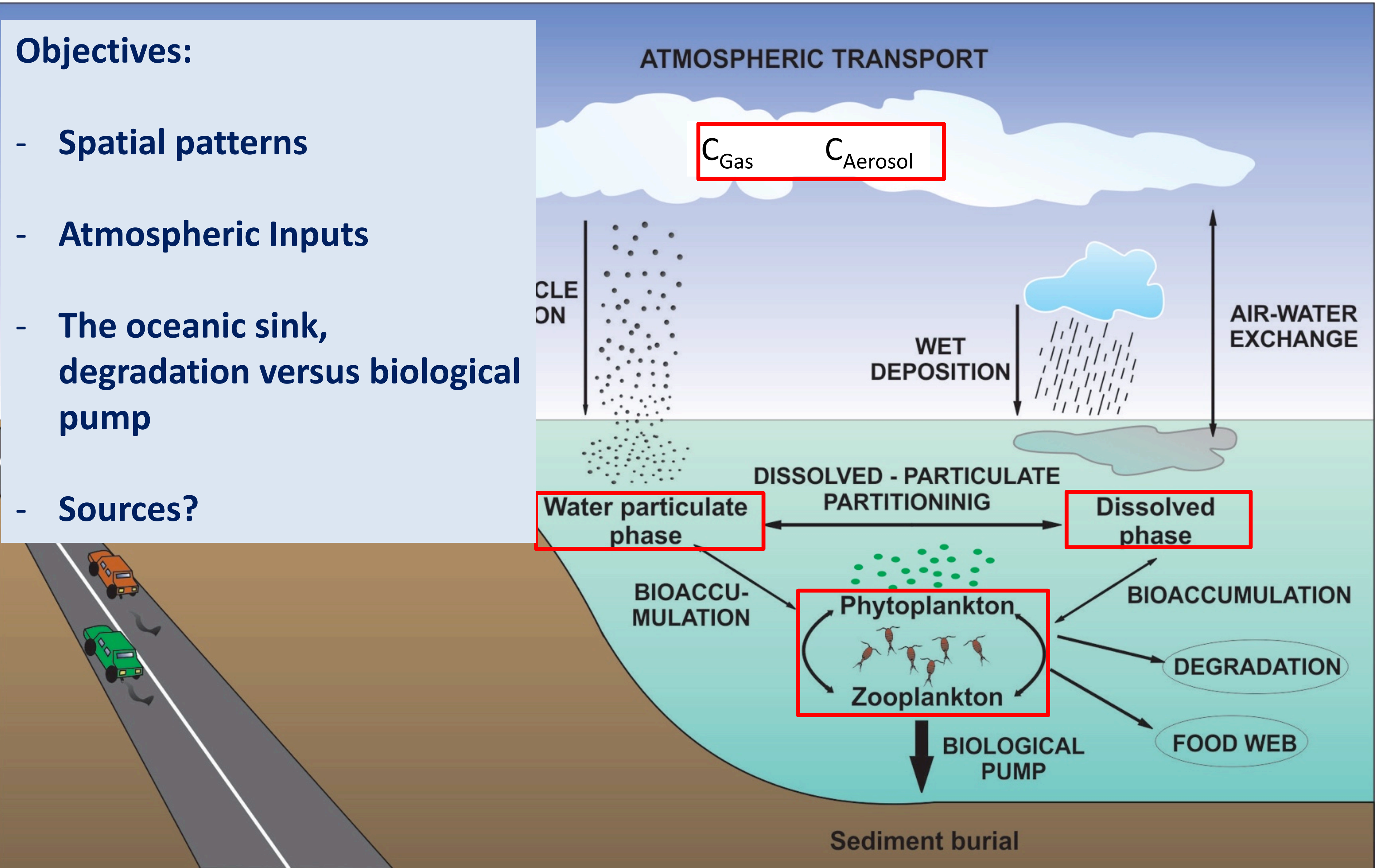


Jordi Dachs
Department of Environmental Chemistry, IDAEA-CSIC
Barcelona, Catalunya, Spain

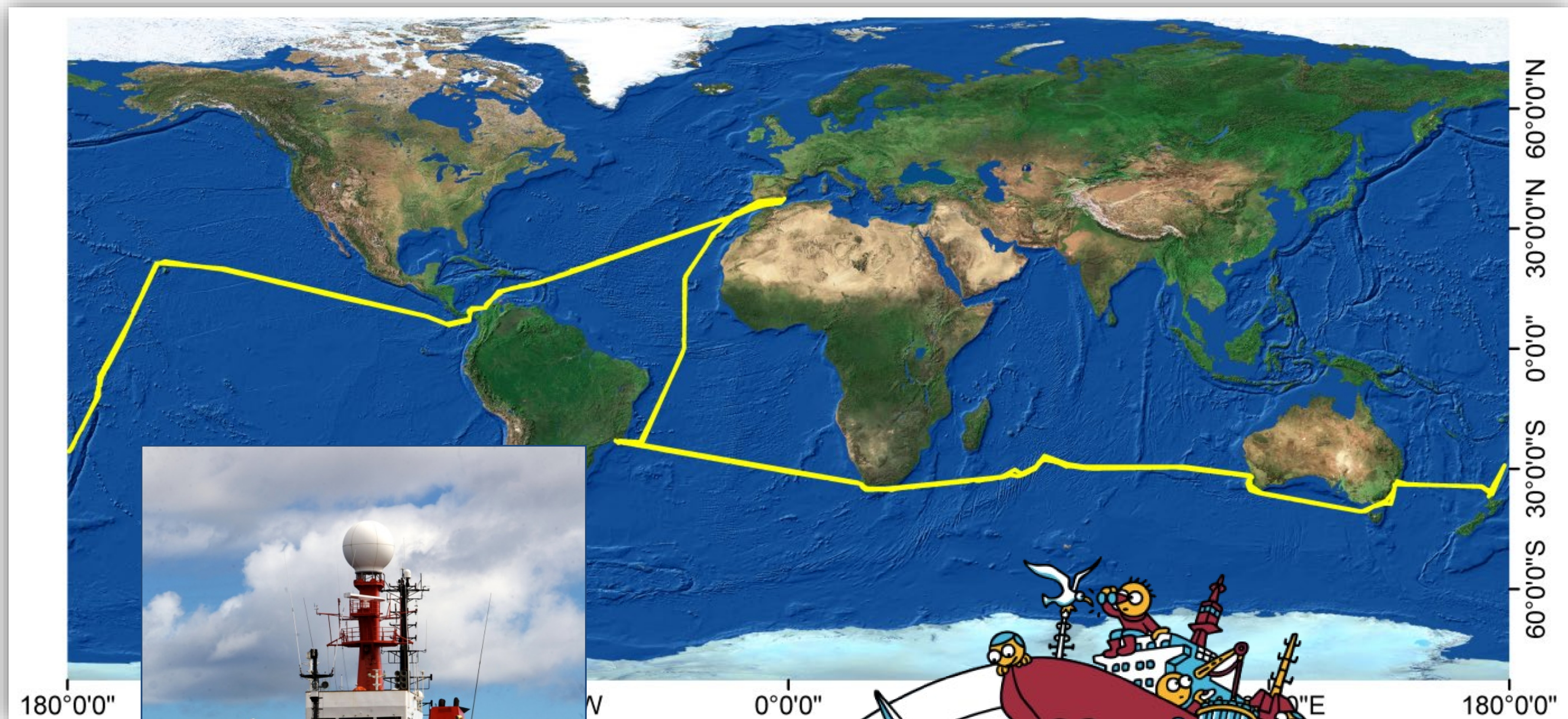
Environmental Transport and Fate of Hydrocarbons

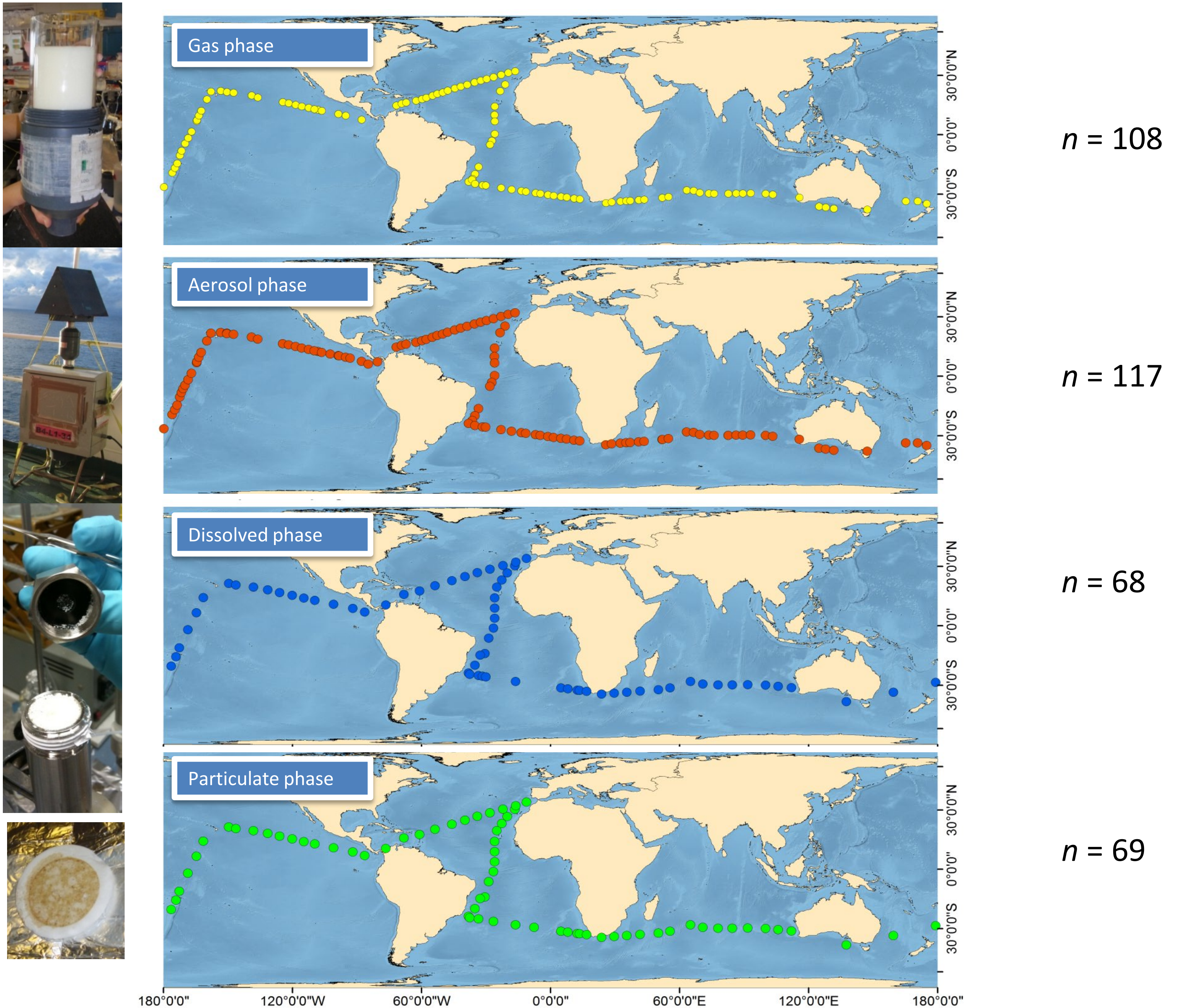
Objectives:

- **Spatial patterns**
- **Atmospheric Inputs**
- **The oceanic sink, degradation versus biological pump**
- **Sources?**



MALASPINA EXPEDITION (2010-2011)



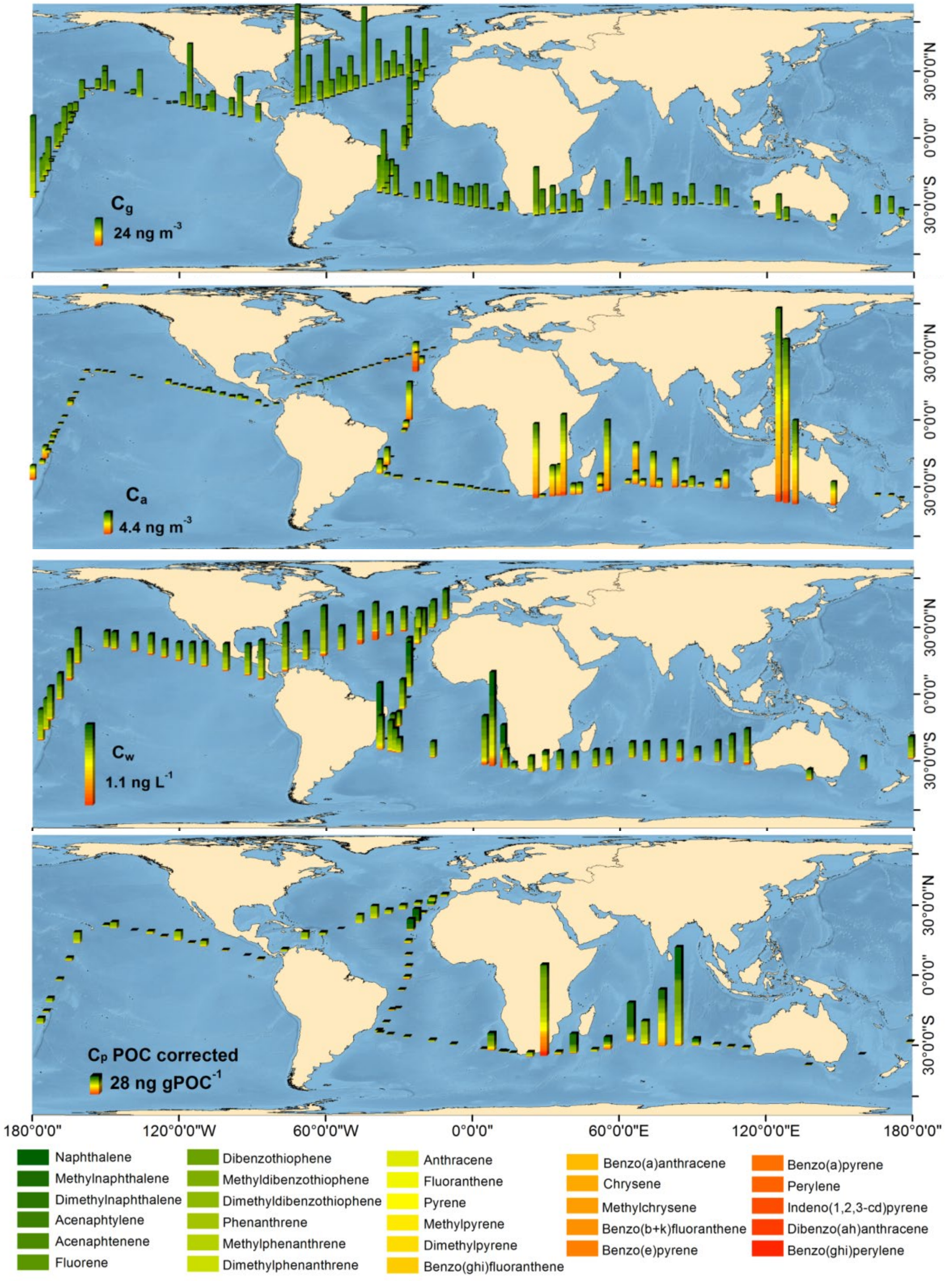

Gas phase
n = 108
Aerosol phase
n = 117
Dissolved phase
n = 68
Particulate phase
n = 69
30°0'0"N
0°0'0"
30°0'0"S
180°0'0"
120°0'0"W
60°0'0"W
0°0'0"
60°0'0"E
120°0'0"E
180°0'0"

Gas Phase

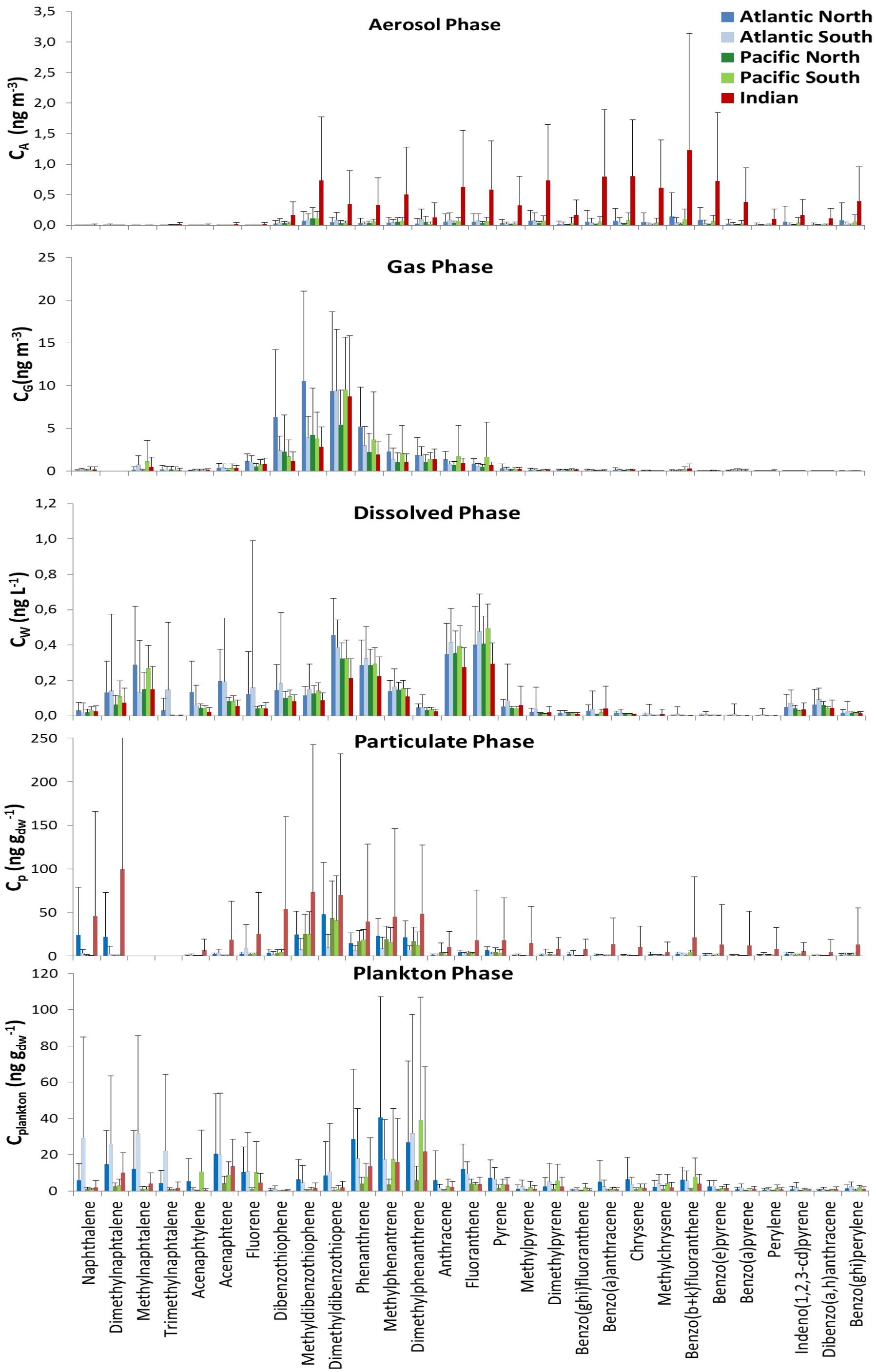
Aerosol Phase

Dissolved Phase

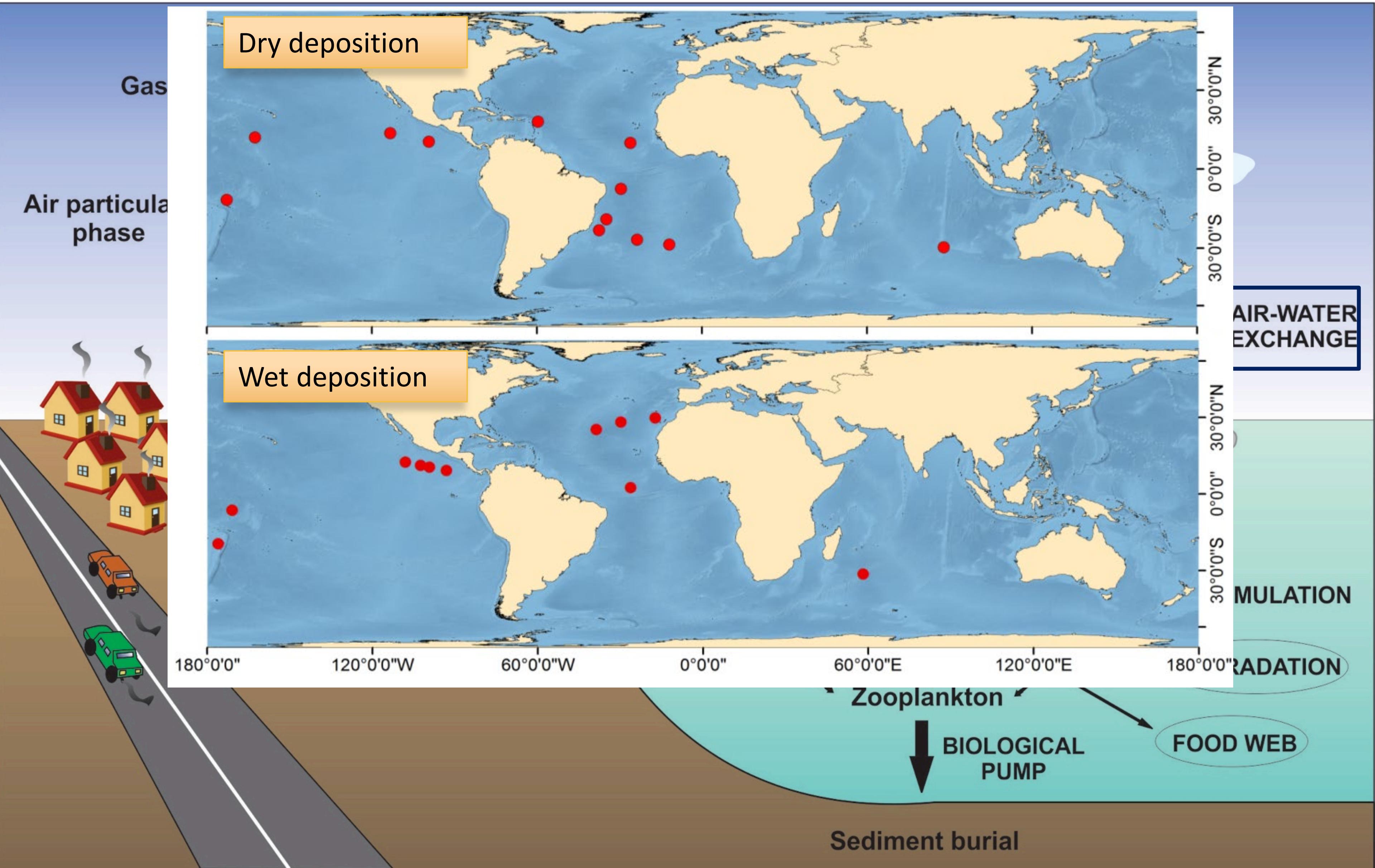
Particulate Phase



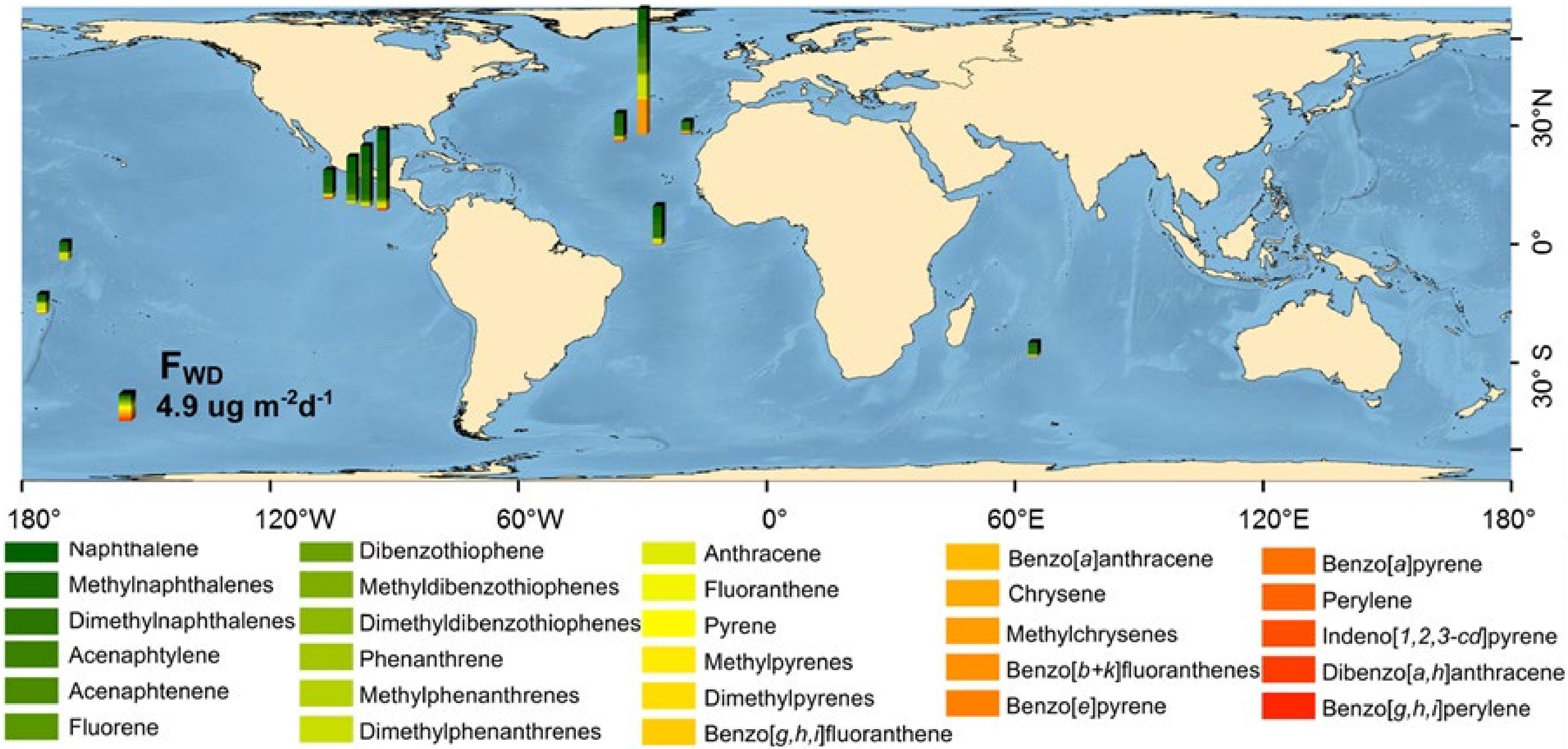
PAH Profiles



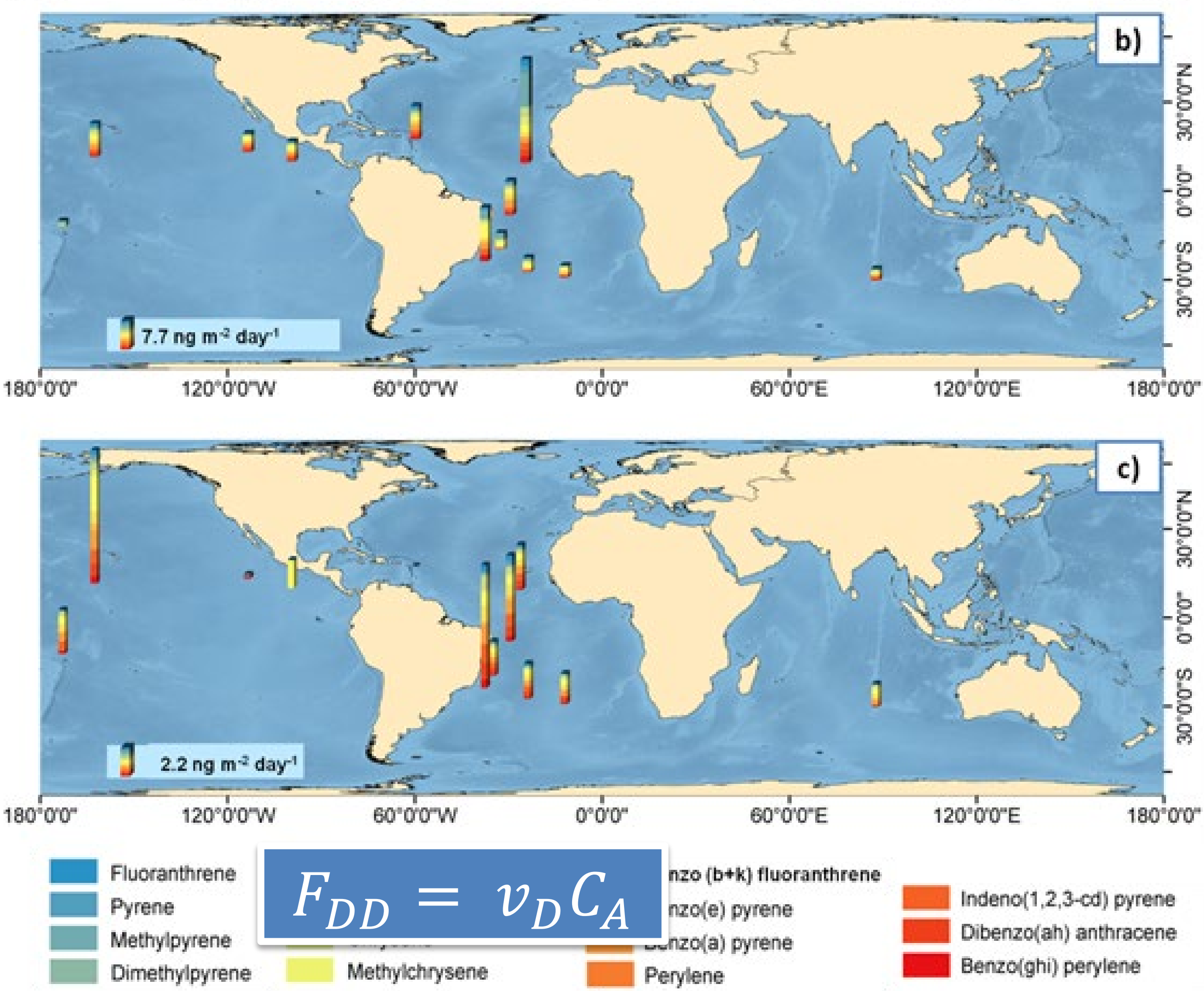
Environmental Transport and Fate of PAHs



Wet Deposition of PAHs



Dry Deposition of Aerosol Bound PAHs



Dry Deposition (0.7 - 2.7 µm)

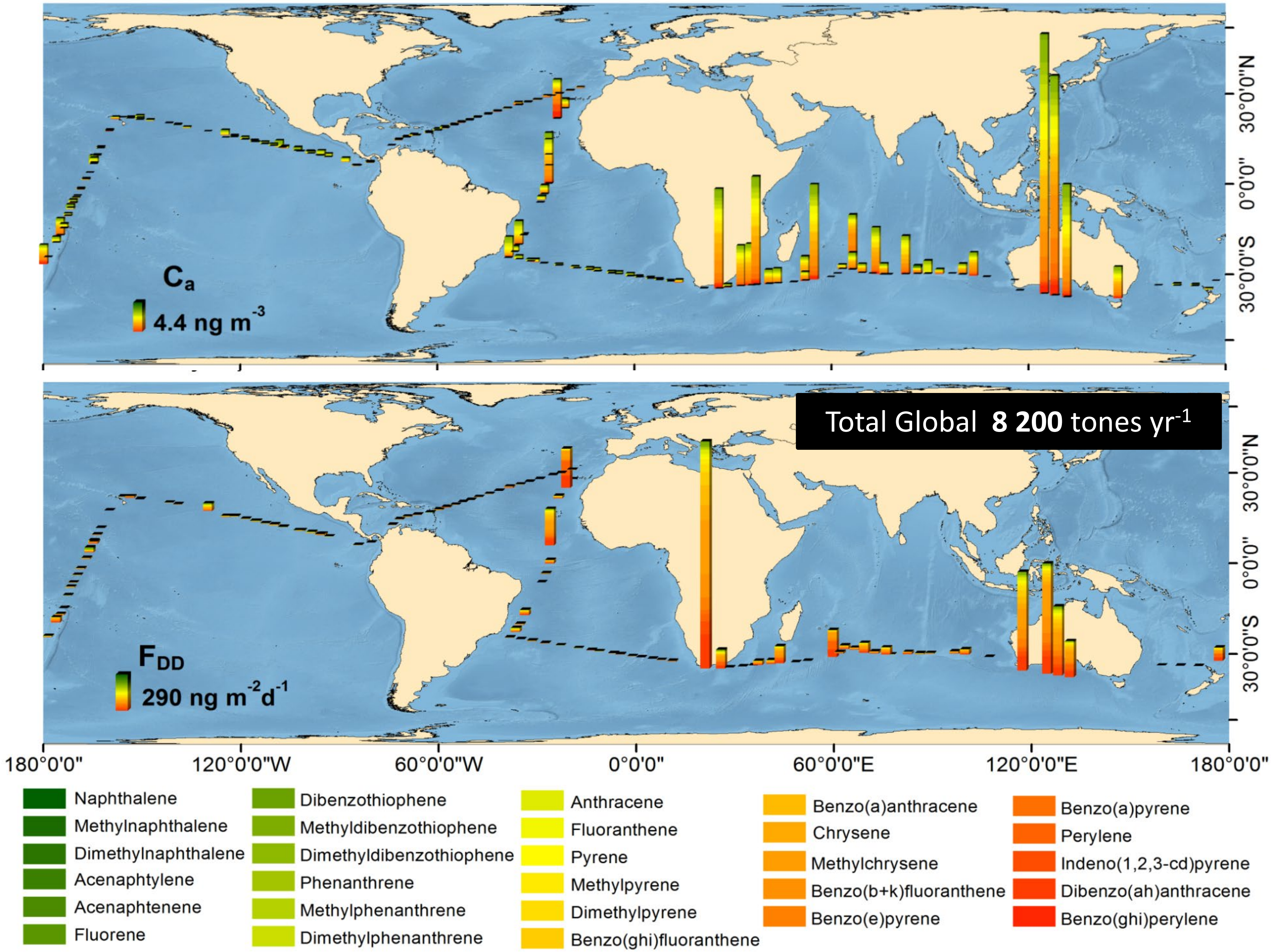
Dry Deposition (> 2.7 µm)

$$F_{DD} = v_D C_A$$

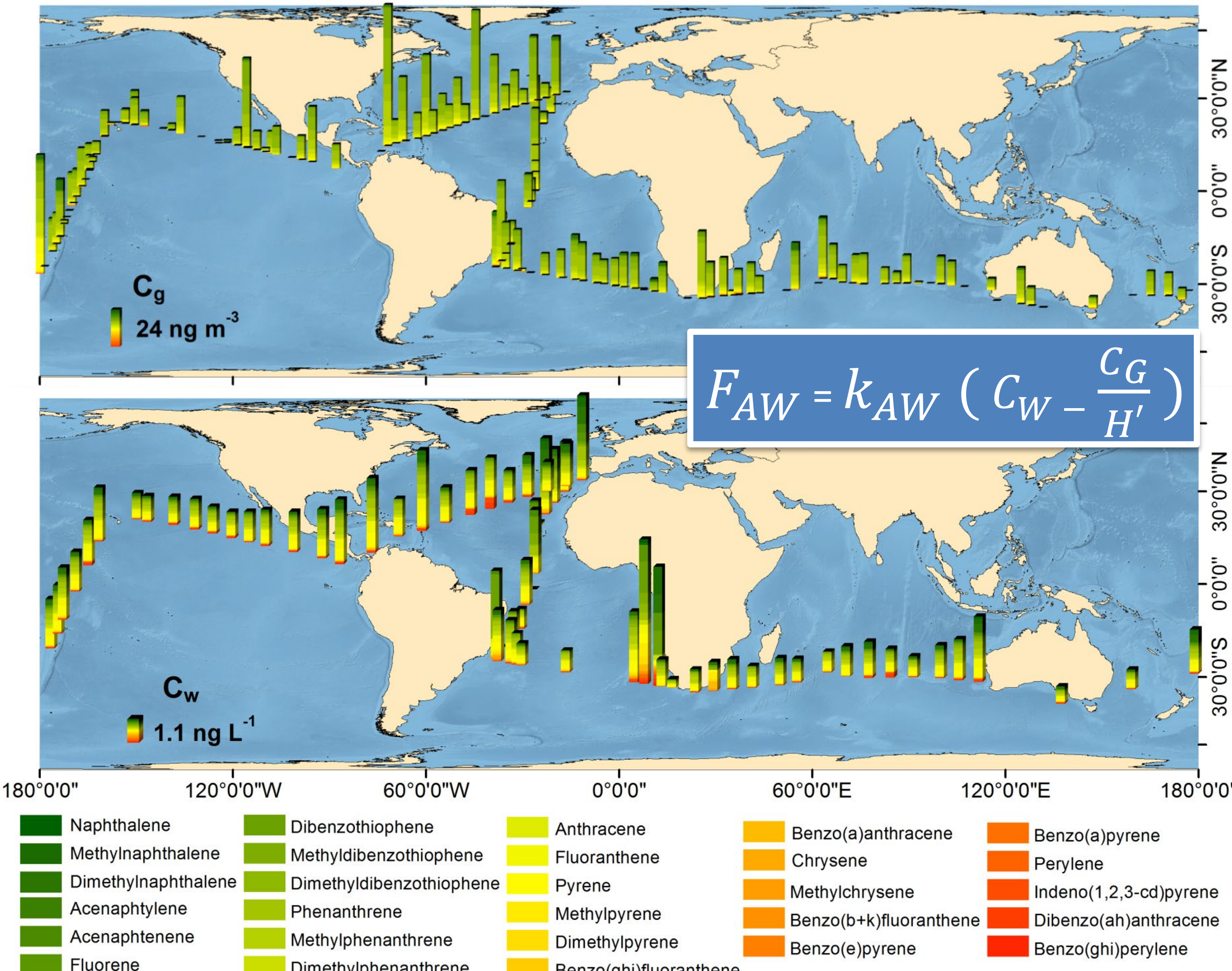
$$Log(v_D) = -0.261\ Log\ (P_L) + 0.387\ U_{10} * Chl_a - 3.082$$

González-Gaya et al. EST 2014

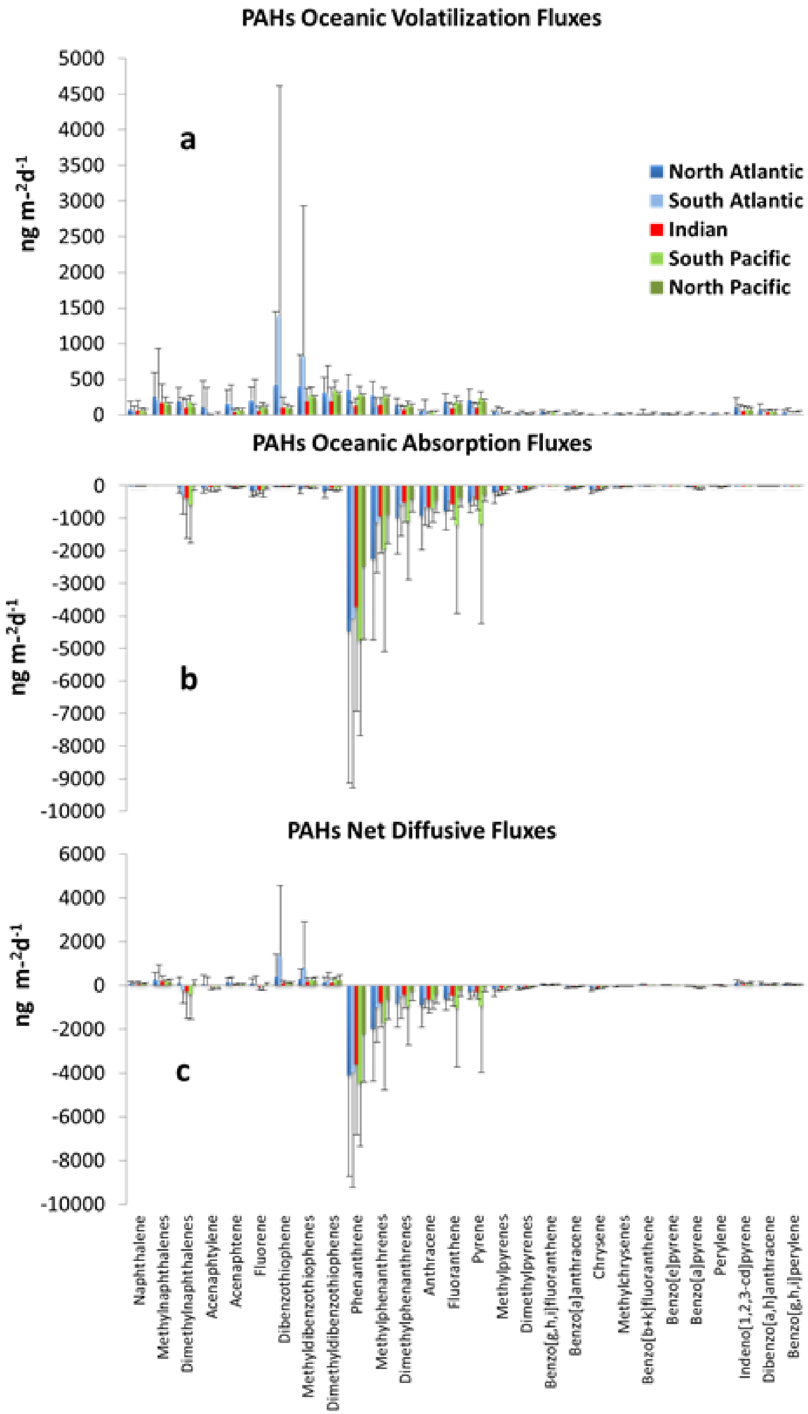
Dry Deposition of Aerosol Bound PAHs



Diffusive Air-Water exchanges of PAHs



$$F_{AW} = k_{AW} \left(C_W - \frac{C_G}{H'} \right)$$



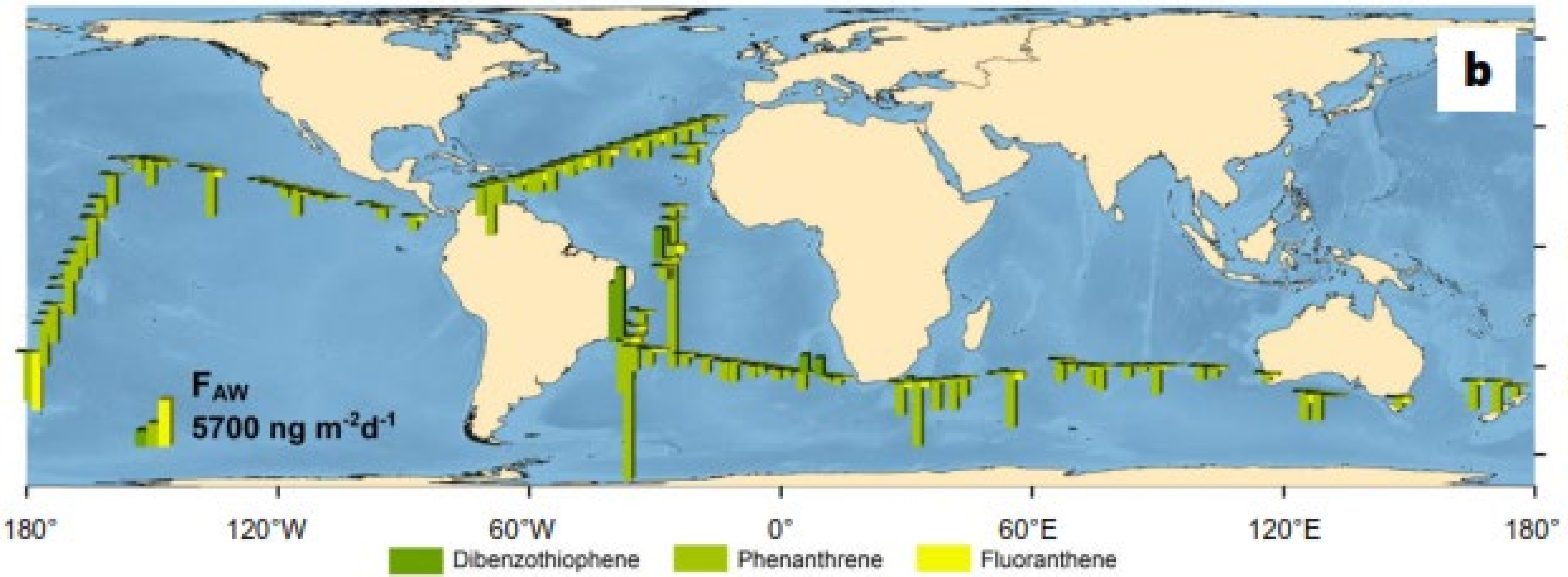
Gross Volatilization:
0.50 Tg y^{-1}

Gross Absorption:
1.59 Tg y^{-1}

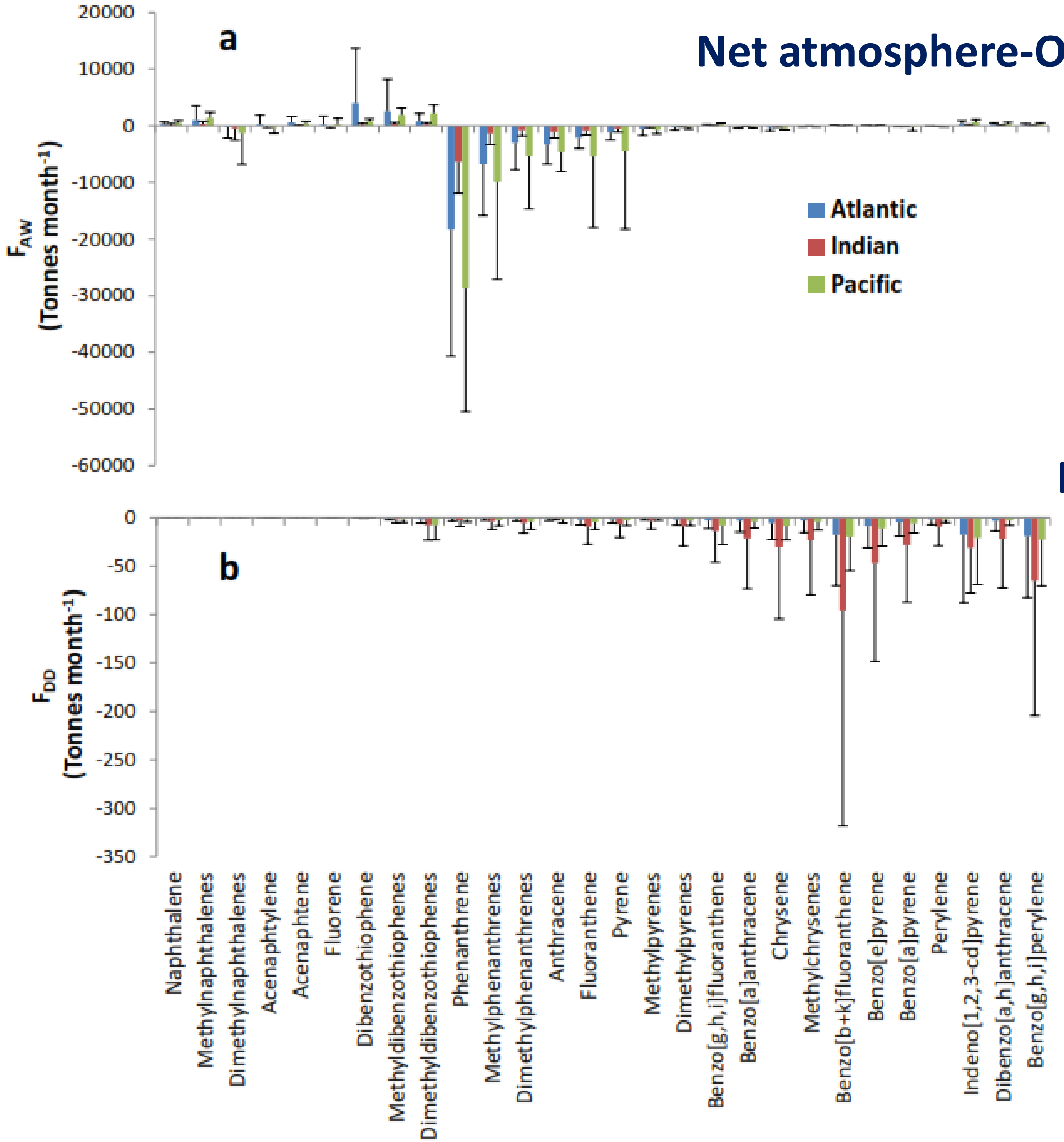
Net atmosphere-Ocean Exchange:
1.09 Tg y^{-1}

González-Gaya et al.
Nature Geoscience 2016

Diffusive Air-Water Exchange of PAHs



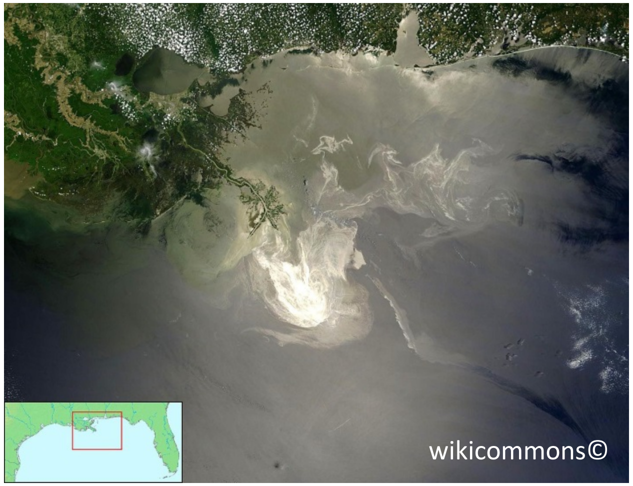
Atmosphere-Ocean Exchange of PAHs



Net atmosphere-Ocean diffusive Exchange: 1.09 Tg y^{-1}

Dry deposition: 0.08 Tg y^{-1}

González-Gaya et al. *Nature Geoscience* 2016



PNAS

SPECIAL FEATURE

Composition and fate of gas and oil released to the water column during the *Deepwater Horizon* oil spill

Christopher M. Reddy[a,1], J. Samuel Arey[b], Jeffrey S. Seewald[a], Sean P. Sylva[a], Karin L. Lemkau[a], Robert K. Nelson[a], Catherine A. Carmichael[a], Cameron P. McIntyre[a], Judith Fenwick[c], G. Todd Ventura[d], Benjamin A. S. Van Mooy[a], and Richard Camilli[c]

[a]Department of Marine Chemistry and Geochemistry, Woods Hole Oceanographic Institution, Woods Hole, MA 02543; [b]Environmental Chemistry Modeling Laboratory, Swiss Federal Institute of Technology at Lausanne (EPFL), 1015 Lausanne, Switzerland; [c]Applied Ocean Physics and Engineering Department, Woods Hole Oceanographic Institution, Woods Hole, MA 02543; and [d]Department of Earth Sciences, University of Oxford, Parks Road, Oxford OX1 3PR, United Kingdom

Edited by John M. Hayes, Woods Hole Oceanographic Institution, Berkeley, CA, and approved June 10, 2011 (received for review January 25, 2011)

Quantitative information regarding the endmember composition of the gas and oil that flowed from the Macondo well during the *Deepwater Horizon* oil spill is essential for determining the oil flow rate, total oil volume released, and trajectories and fates of hydrocarbon components in the marine environment. Using isobaric gas-tight samplers, we collected discrete samples directly above the Macondo well on June 21, 2010, and analyzed the

processes complicate efforts to differentiate aqueous dissolution from other loss processes, few studies have attempted to quantify aqueous dissolution of hydrocarbons to the water column (11). Petroleum released from the Macondo well at 1.5-km depth, however, allows the partitioning of hydrocarbons into the aqueous phase to be studied in the absence of atmospheric evaporation.

To acquire a representative endmember of gas and oil, two

Table S1. Quantities of individual gases released from the Macondo well as calculated in this study and by Valentine et al. (1), Kessler et al. (2), and Joye et al. (3)

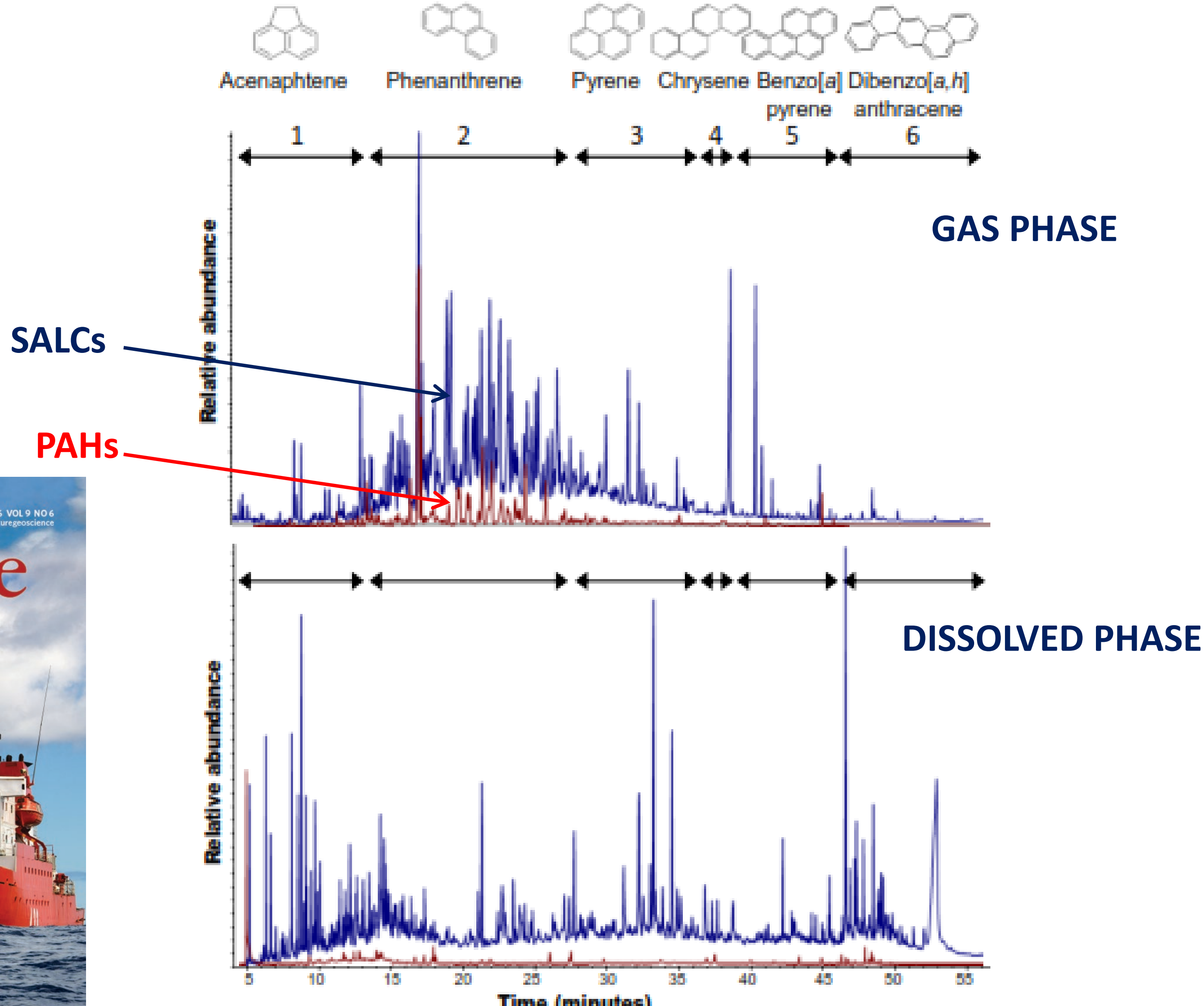
		Total hydrocarbons released from the Macondo well			
Analyte	MW-1 content, %	Current study*, g	Valentine et al. (1)[†], g	Kessler et al. (2)[‡], g	Joye et al. (3)[§], g
Gas[¶]					
Methane	82.5	1.0×10^{11}	2.1×10^{11}	1.5×10^{11} to 2.0×10^{11}	3.5×10^{11} to 4.9×10^{11}
Ethane	8.3	1.9×10^{10}	3.6×10^{10}	2.6×10^{10} to 3.5×10^{10}	2.5×10^{10} to 3.5×10^{10}
Propane	5.3	1.8×10^{10}	2.8×10^{10}	2.0×10^{10} to 2.8×10^{10}	1.4×10^{10} to 1.9×10^{10}
Isobutane	0.97	4.7×10^{9}	—	—	—
n-butane	1.9	1.0×10^{10}	—	—	1.3×10^{10} to 1.8×10^{10}
n-alkanes	0.15	8.1×10^{10}	—	—	—
Branched alkanes	0.26	1.4×10^{11}	—	—	—
Biomarkers	0.016	$8.8 \times 10^{[illegible]}$	—	—	—
Others	0.18	1.5×10^{11}	—	—	—
Polars[††]	0.10	5.4×10^{10}	—	—	—
Total oil (GC-amenable and polars)		5.3×10^{11}	—	—	6.0×10^{11} to 8.4×10^{11}
Total gas and oil		6.9×10^{11}	—	—	—

Polycyclic aromatic hydrocarbons	0.039	2.1×10^{10}

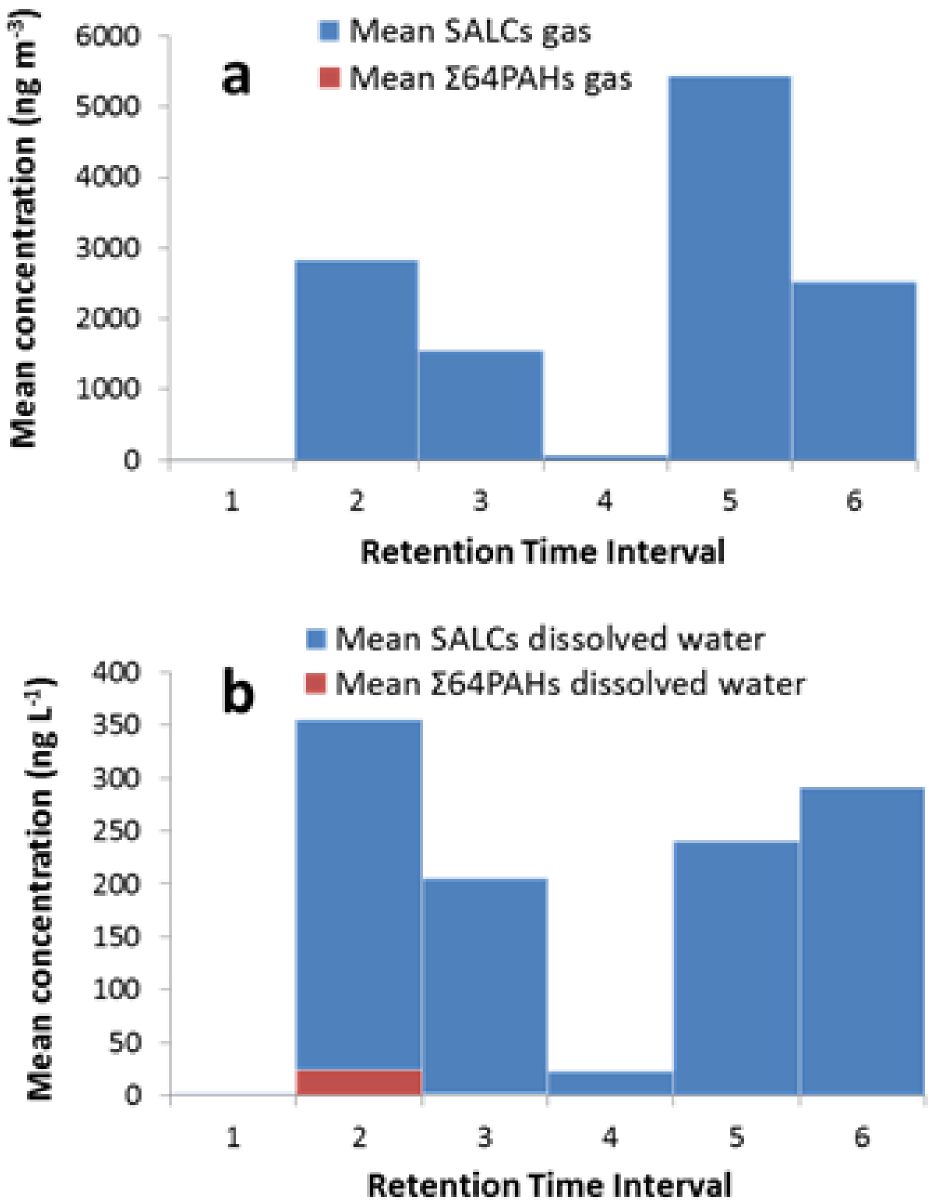
Total Global **1.09×10^{12}** g yr^{-1}

Semivolatile Aromatic-like Compounds (SALCs)

(UCM and resolved compounds of the aromatic fraction)



SEMIVOLATILE AROMATIC-LIKE COMPOUNDS (SALCs)

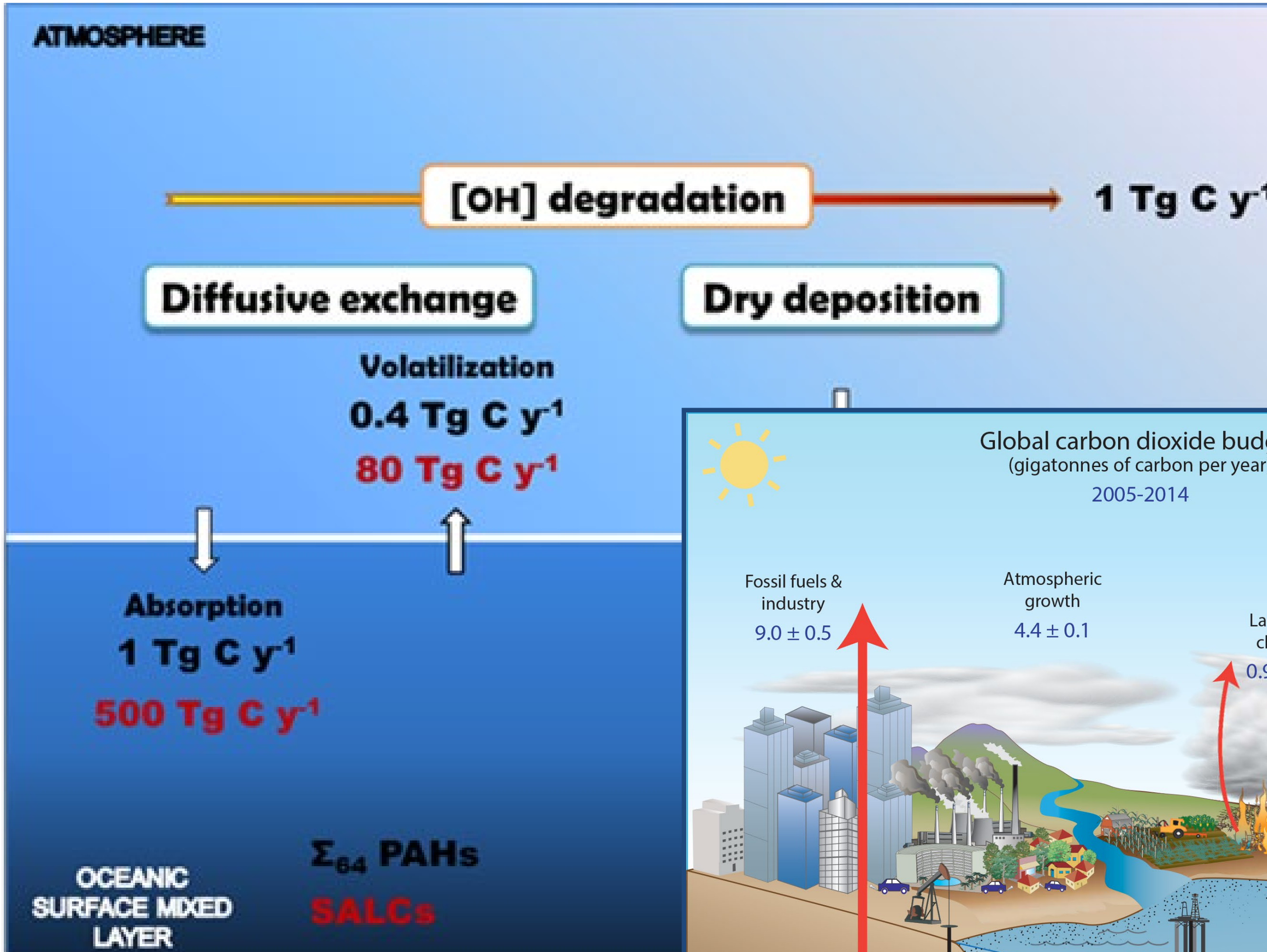


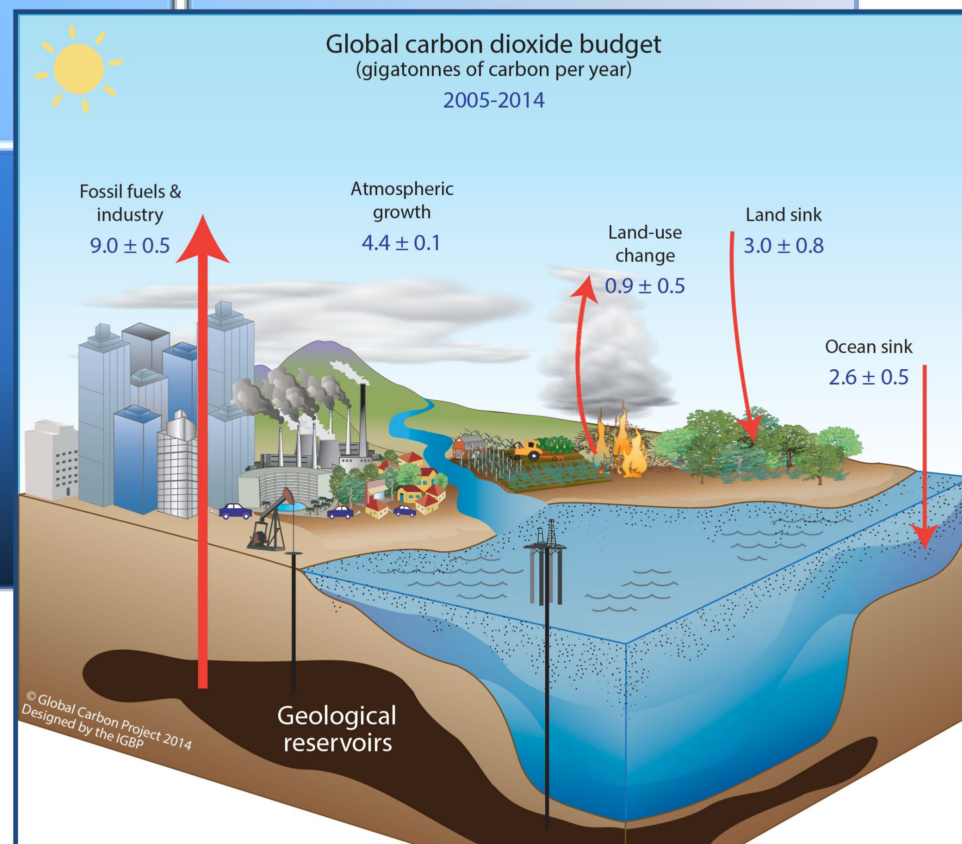
GAS PHASE

DISSOLVED PHASE

González-Gaya et al.
Nature Geoscience 2016

The PAH and SALC contribution to the marine carbon cycle





Le Queré et al. 2015

Uncertainty of a factor of 2!

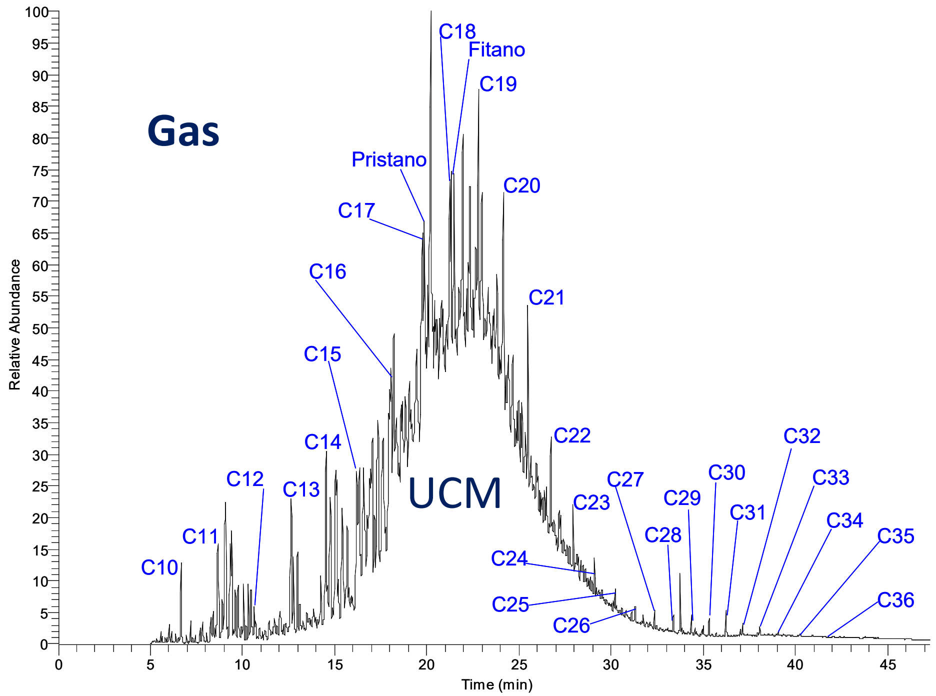
SALCs input is about 15% of CO_2 inputs to the global oceans

Aliphatic UCM

NE Atlantic Atmosphere

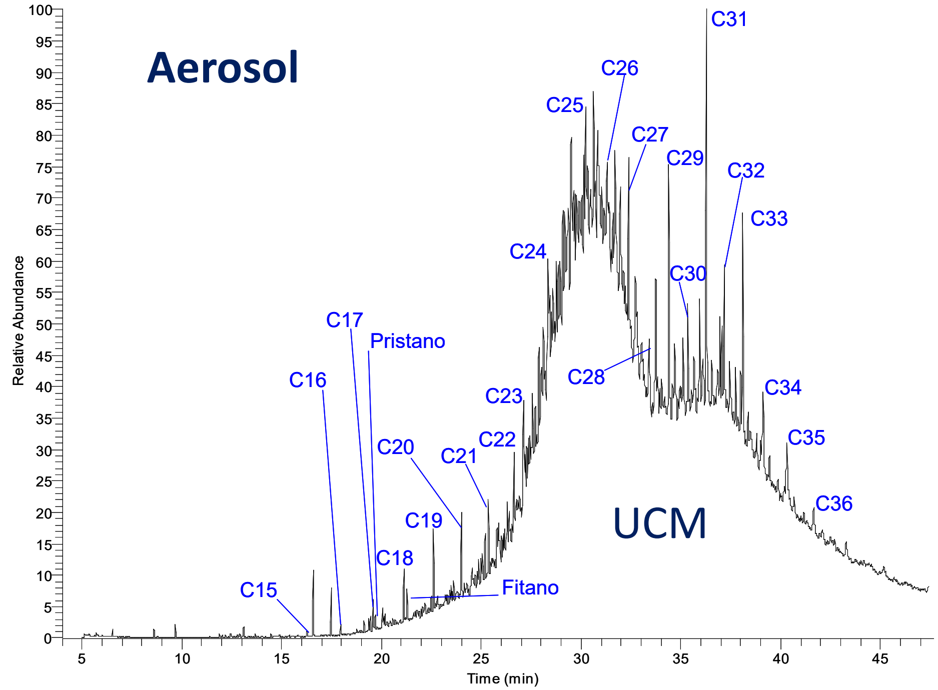
Gas Phase --- 300 nmol C m^{-3}

CPI = 1.2



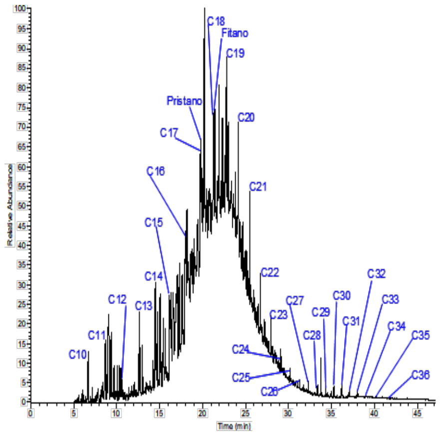
Aerosol Phase --- 40 nmol C m^{-3}

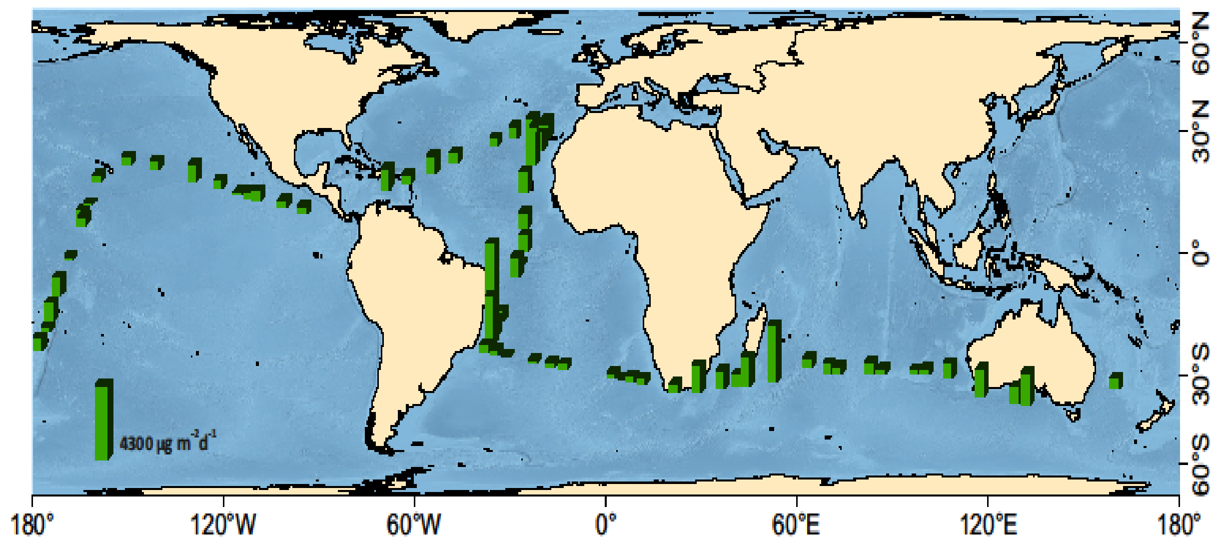
CPI = 1.9



Unpublished results

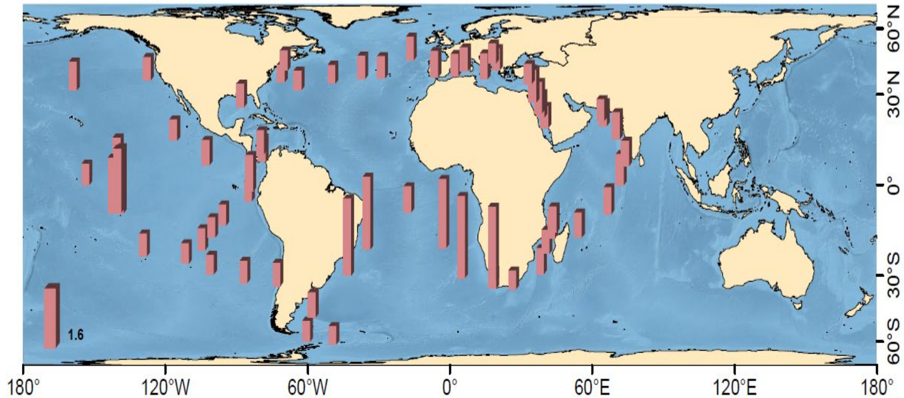
Air to Ocean Exchange of Aliphatic Hydrocarbons and Microbial Degradation





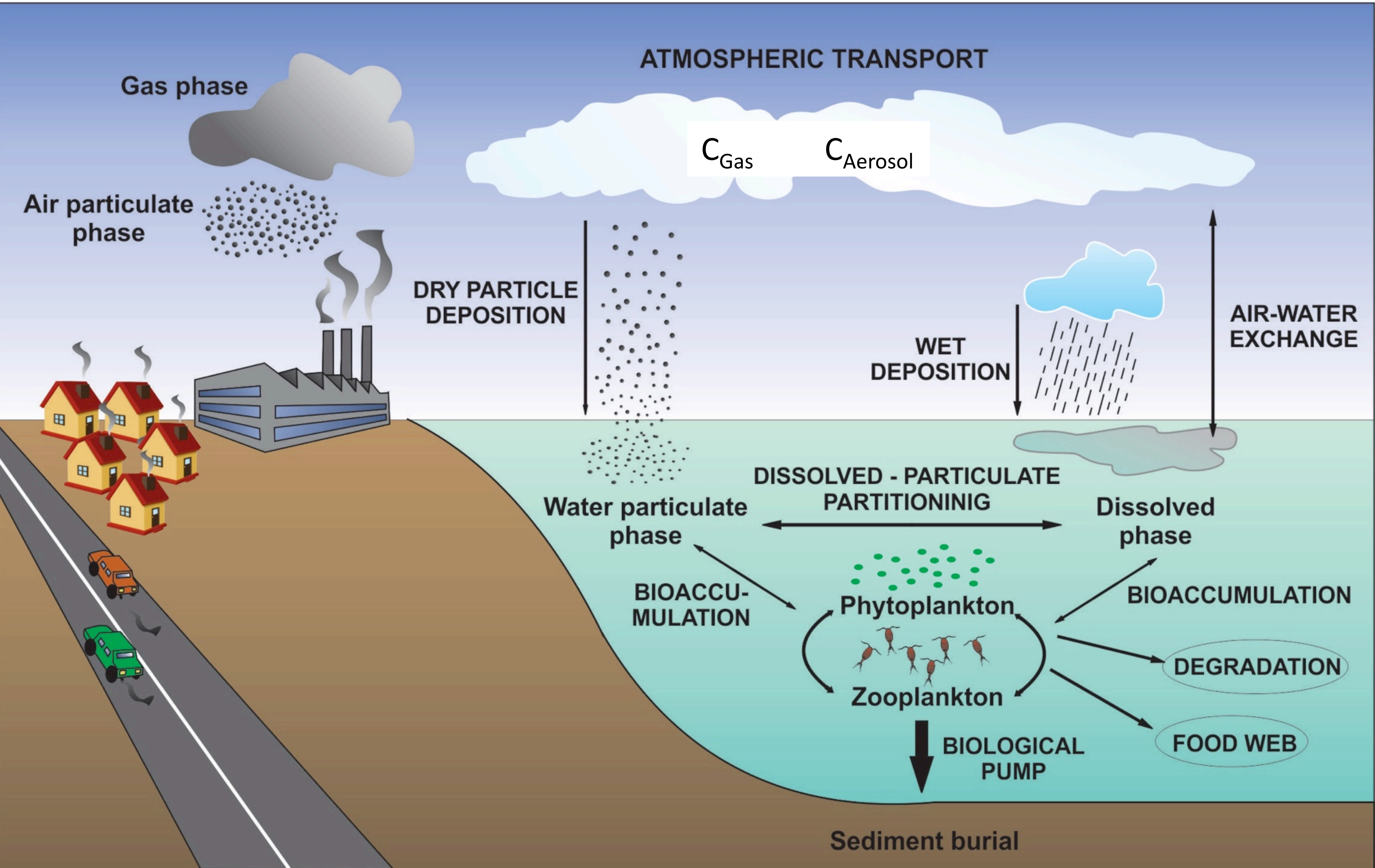
Up to 90 TgC y^{-1} of aliphatic hydrocarbons (mainly UCM) enter the global oceans (with a large uncertainty)

Fa desaturase (copies $cell^{-1}$)

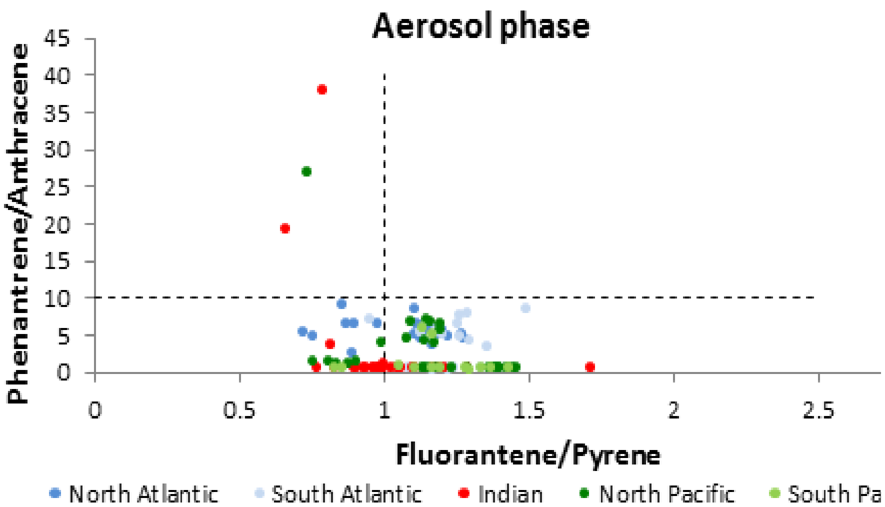


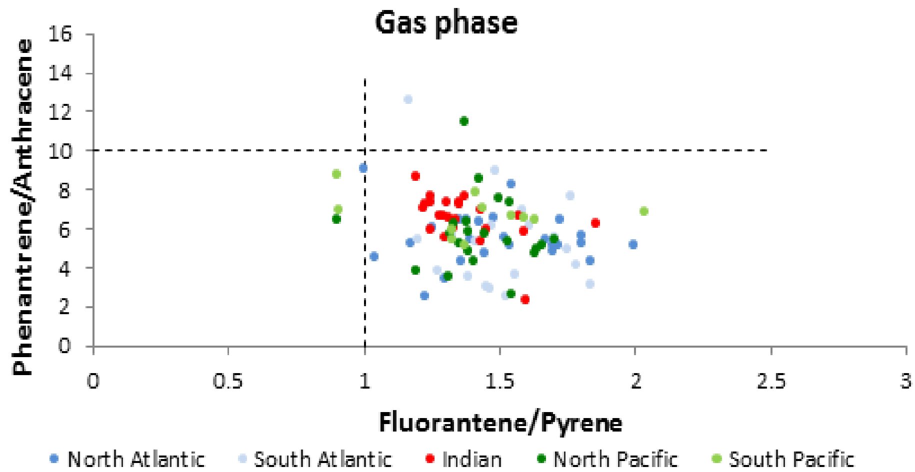
Dachs et al. Unpublished 2021

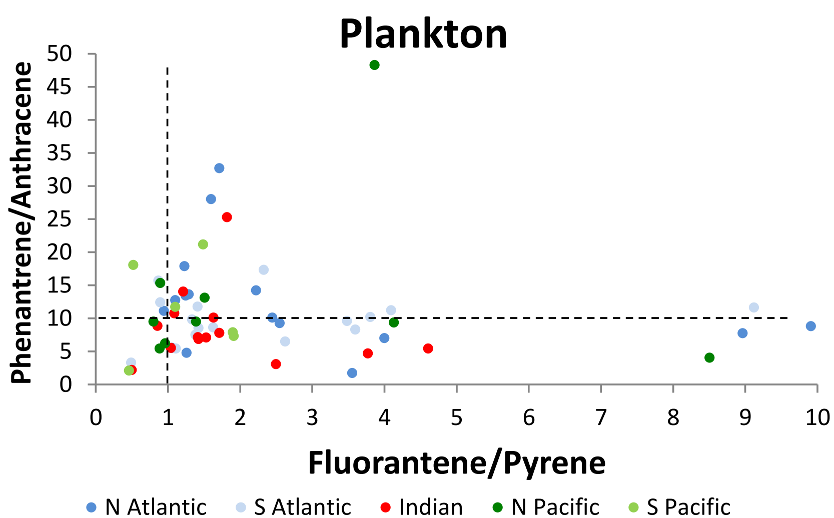
Which are the sources of SALCs and PAHs?

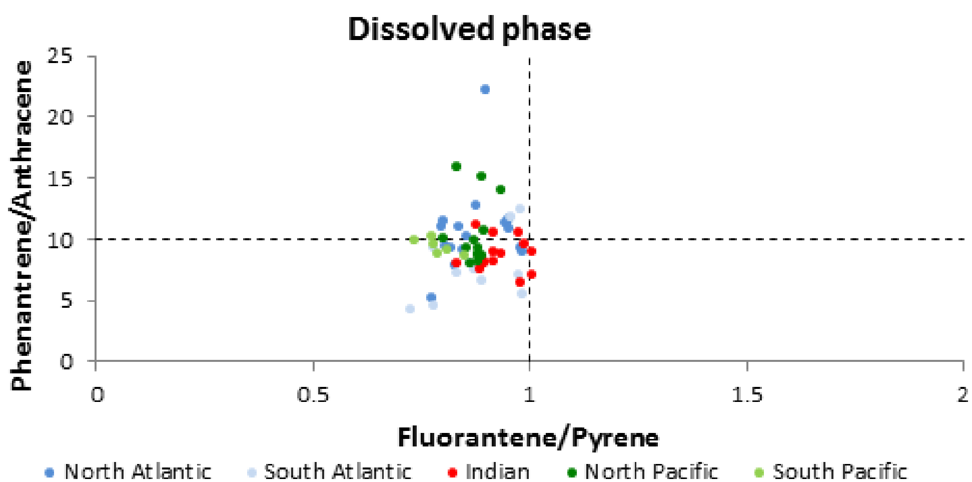


PAHs diagnostic ratios









Environmental Science & Technology
Article
pubs.acs.org/est

Unresolved Complex Mixture (UCM) in Coastal Environments Is Derived from Fossil Sources

Helen K. White,*,† Li Xu,‡ Paul Hartmann,§ James G. Quinn,|| and Christopher M. Reddy⊥

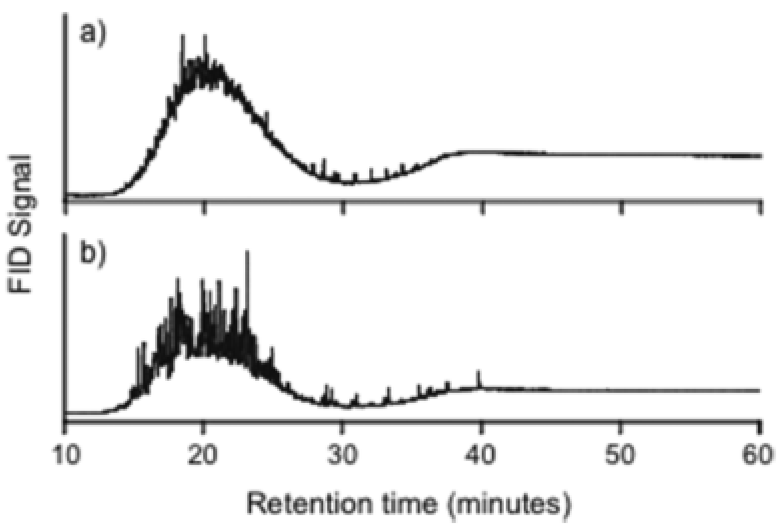
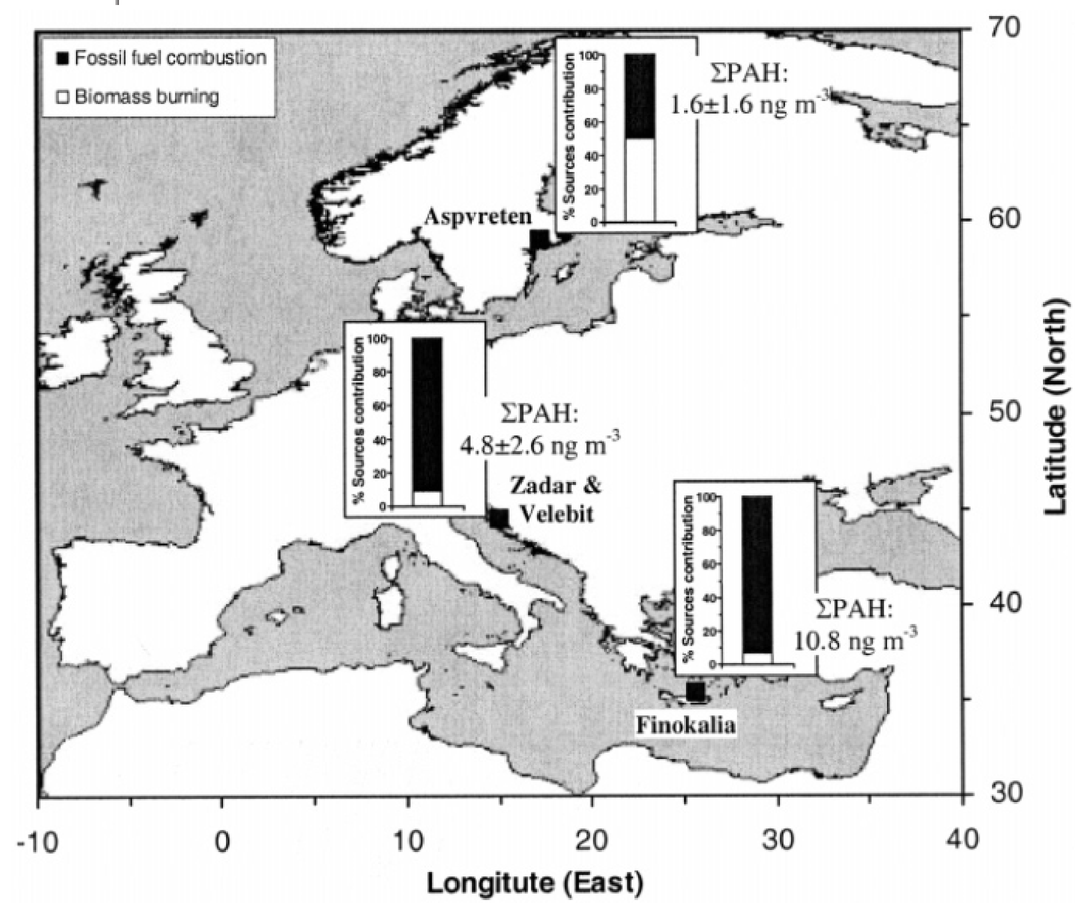


Figure 2. Unresolved complex mixture (UCM) from West Falmouth sediment (14–16 cm): (a) f_1 aliphatic fraction and (b) f_2 aromatic fraction.

More than 90% is fossil derived

Contribution of Biomass Burning to Atmospheric Polycyclic Aromatic Hydrocarbons at Three European Background Sites

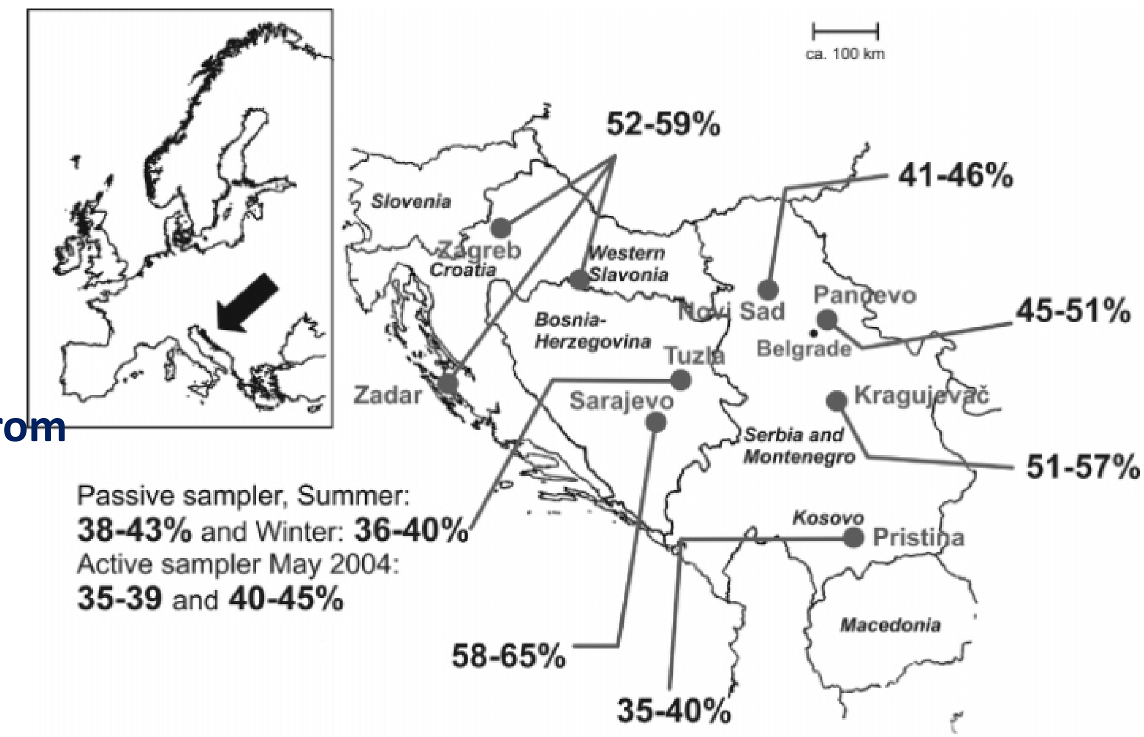
MANOLIS MANDALAKIS,[†]
ÖRJAN GUSTAFSSON,[*,†]
TOMAS ALSBERG,[†]
ANNA-LENA EGEBÄCK,[†]
CHRISTOPHER M. REDDY,[‡] LI XU,[‡]
JANA KLANOVA,[§] IVAN HOLOUBEK,[§]
EURIPIDES G. STEPHANOU[‖]



From 10% to 60% of PAHs are modern carbon, it could be more for some individual PAHs

Source Apportionment of Atmospheric PAHs in the Western Balkans by Natural Abundance Radiocarbon Analysis

ZDENEK ZENCAK,[†] JANA KLANOVA,[‡] IVAN HOLOUBEK,[‡] AND ÖRJAN GUSTAFSSON*,[†]



From 35% to 65% of PAHs are from modern carbon, ….

ARTICLE

pubs.acs.org/est

Ubiquitous Net Volatilization of Polycyclic Aromatic Hydrocarbons from Soils and Parameters Influencing Their Soil−Air Partitioning

Ana Cabrerizo,[†] Jordi Dachs,[†,*] Claudia Moeckel,[‡] María-José Ojeda,[†] Gemma Caballero,[†] Damià Barceló,[†] and Kevin C. Jones[‡]

AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

10.1002/2014GB004910

Sources and fate of polycyclic aromatic hydrocarbons in the Antarctic and Southern Ocean atmosphere

Key Poi

• The at

Article

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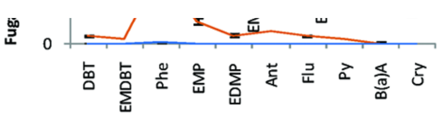
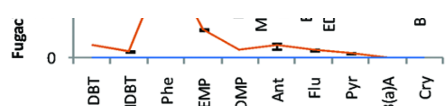
Diurnal Variations of Air-Soil Exchange of Semivolatile Organic Compounds (PAHs, PCBs, OCPs, and PBDEs) in a Central European Receptor Area

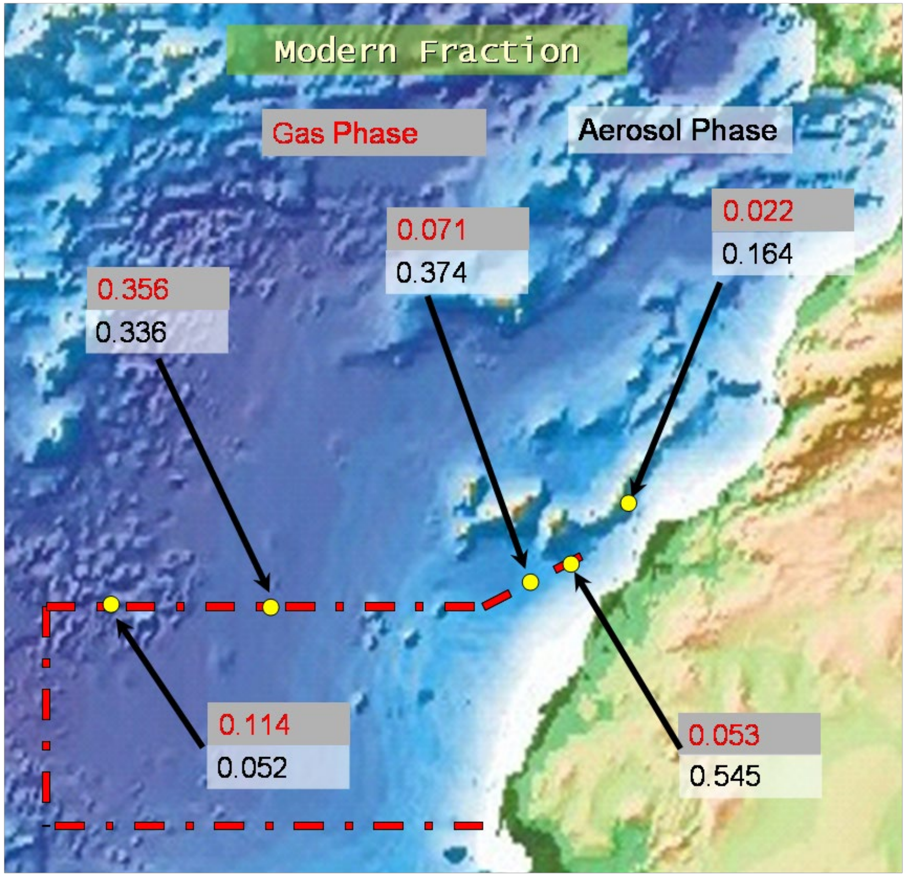
Céline Degrendele,[†] Ondřej Audy,[‡] Jakub Hofman,[‡] Jiři Kučerik,[§] Petr Kukučka,[‡] Marie D. Mulder,[‡] Petra Přibylová,[‡] Roman Prokeš,[‡] Milan Šáňka,[‡] Gabriele E. Schaumann,[§] and Gerhard Lammel[*,†,‡]





Isotopic Signature of Semivolatile Aliphatic Fraction

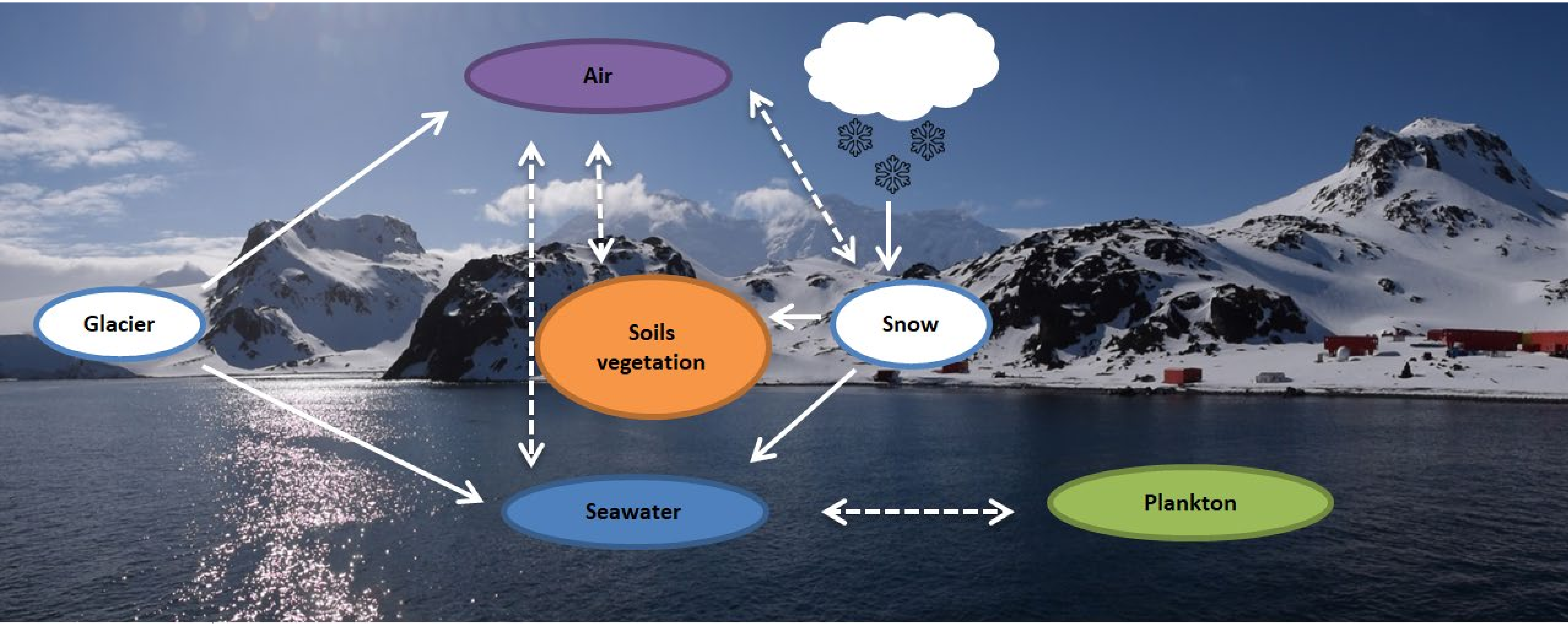
Sample ID	δ ^{13}C		Δ ^{14}C	
	Gas Phase	Aerosol Phase	Gas Phase	Aerosol Phase
Point # 1	-27.48‰	-28.19‰	-978.2‰	- 836.7‰
Point # 2	-27.33‰	-27.82‰	-947.6‰	-458.9‰
Point # 3	-27.42‰	-27.47‰	-930.0‰	-654.9‰
Point # 4	-27.26‰	-27.71‰	-646.0‰	-666.0‰
Point # 5	-27.53‰	-27.60‰	-886.5‰	-948.1‰



- Continental sources dominate over marine ones, as carbon isotopic data are enriched in ^{13}C
- Radiocarbon data (^{14}C) indicates that modern carbon in more abundant in open ocean than close to the coast, but overall, old carbon dominates

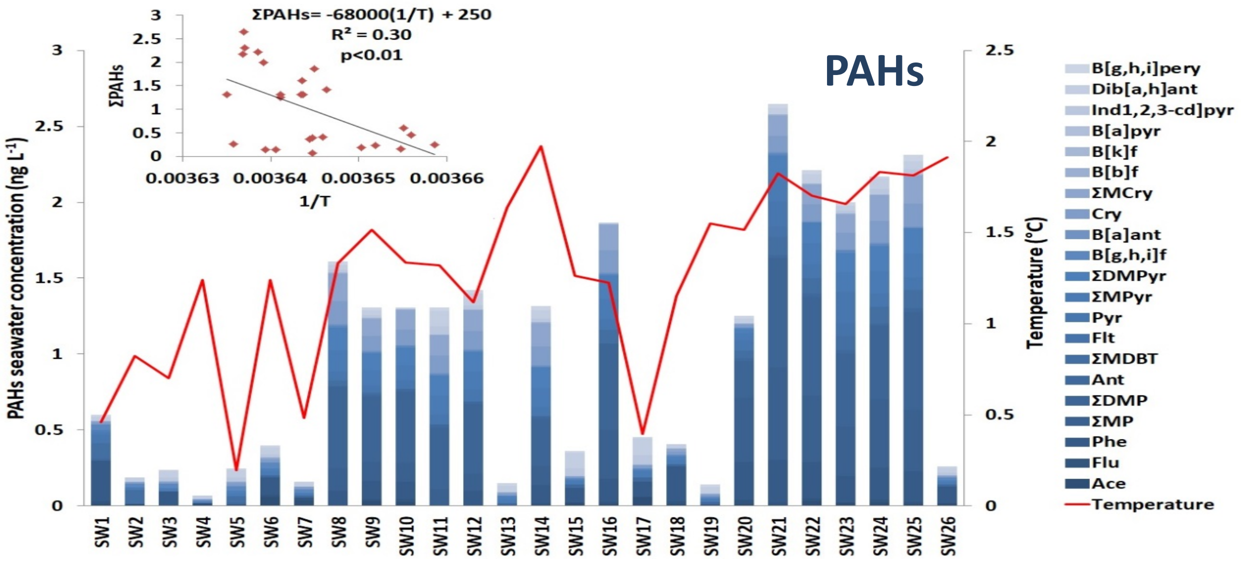
Dachs, J. Unpublished

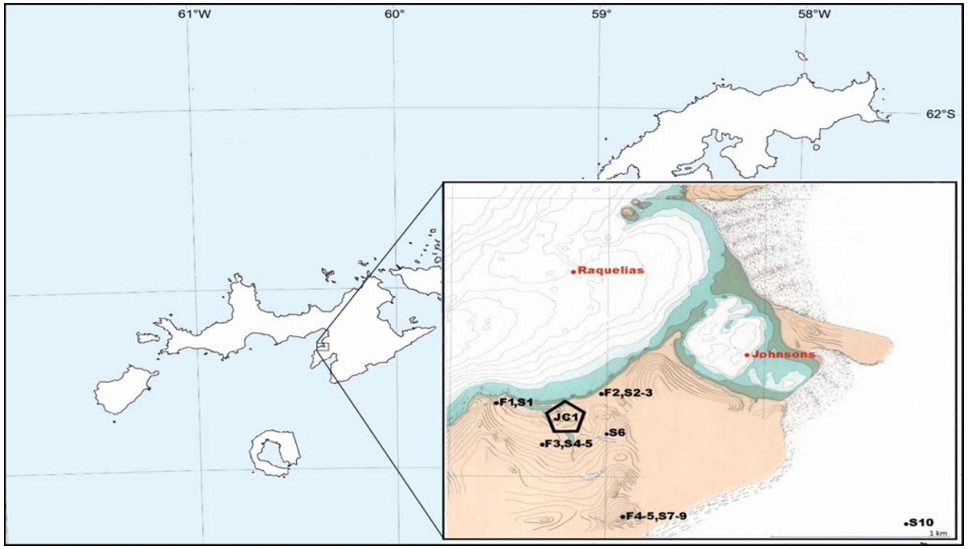
Atmosphere-Land-Ocean Transport of PAHs at Coastal Antarctica



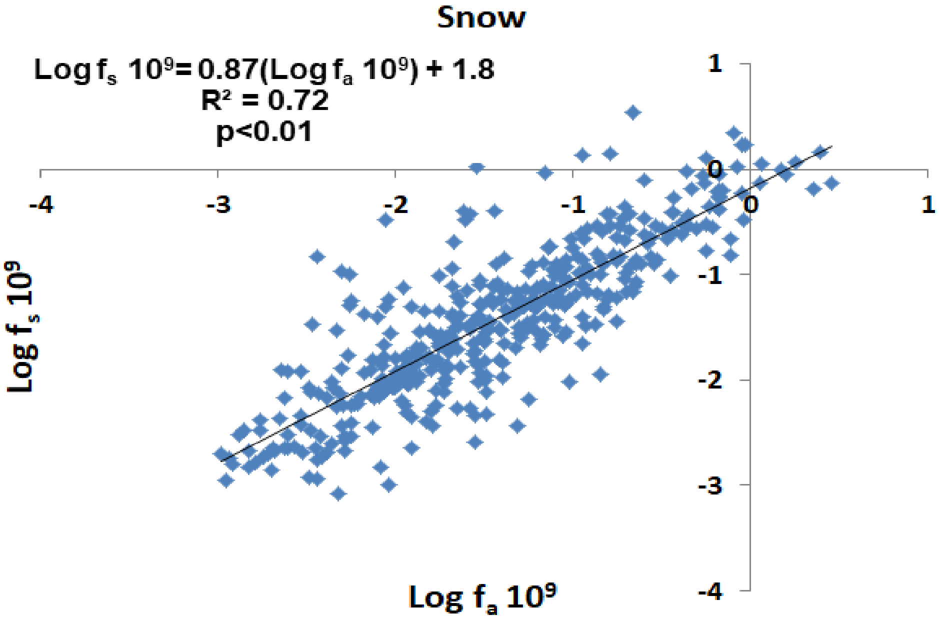
- Air-water and air-soil diffusive Exchange
- Role of snow deposition and melting

Semivolatile Organic Pollutants in Seawater

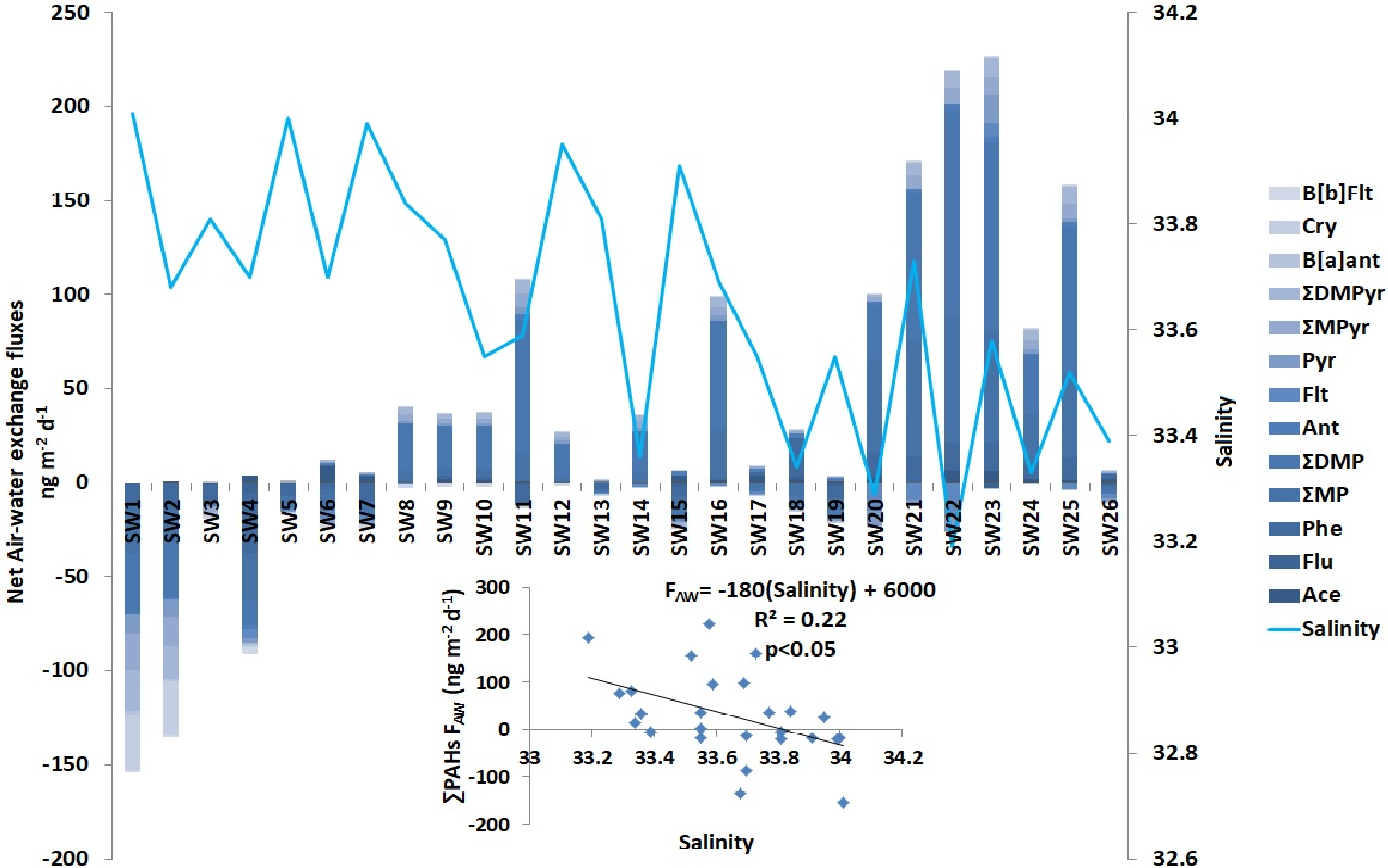




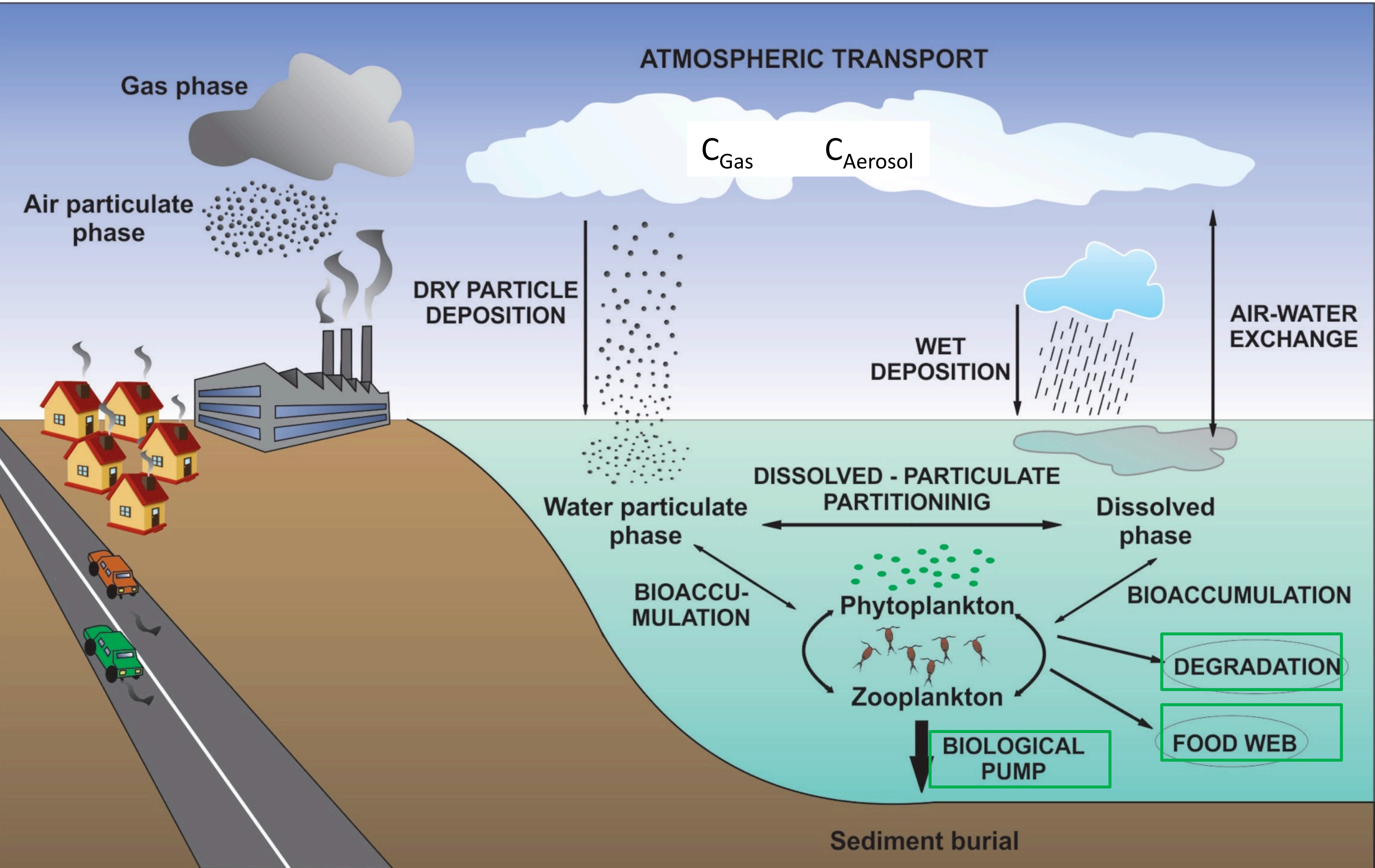
Snow-Air Coupling of PAHs



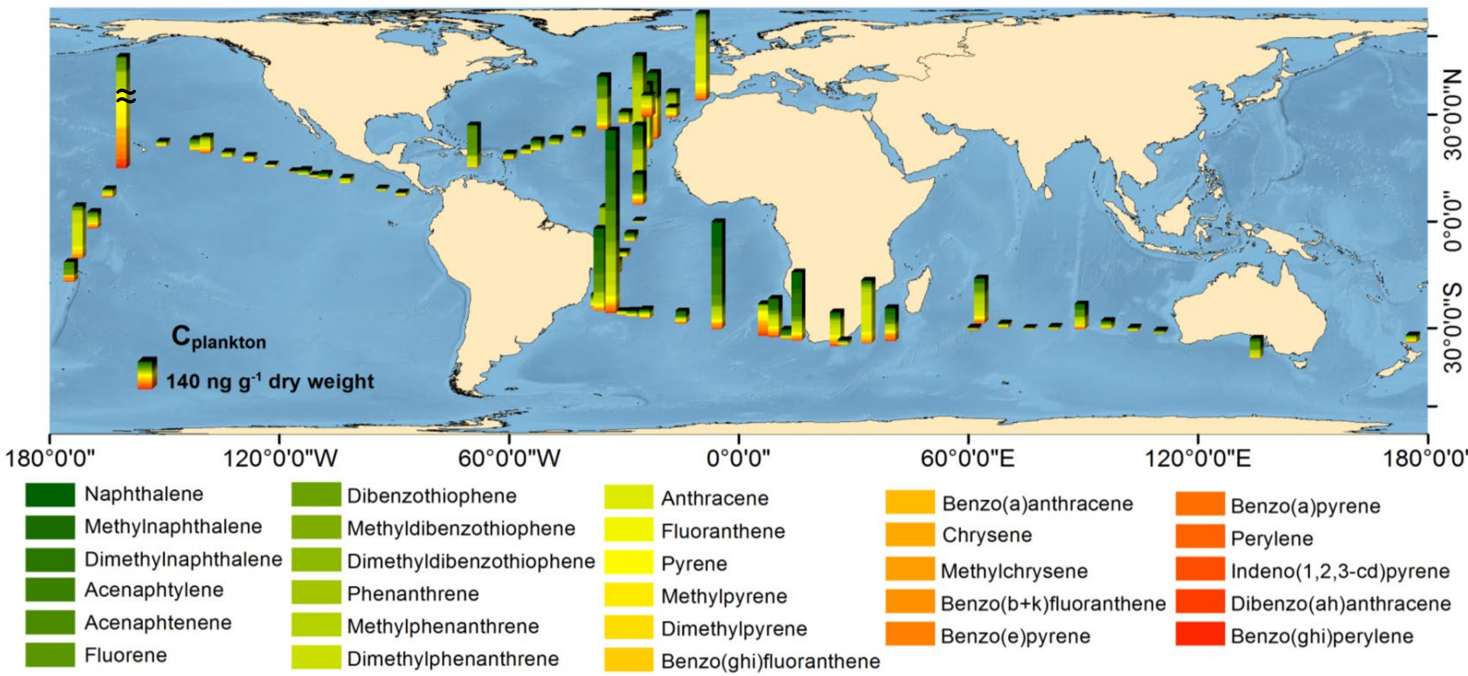
Diffusive Air-water Exchange of PAHs

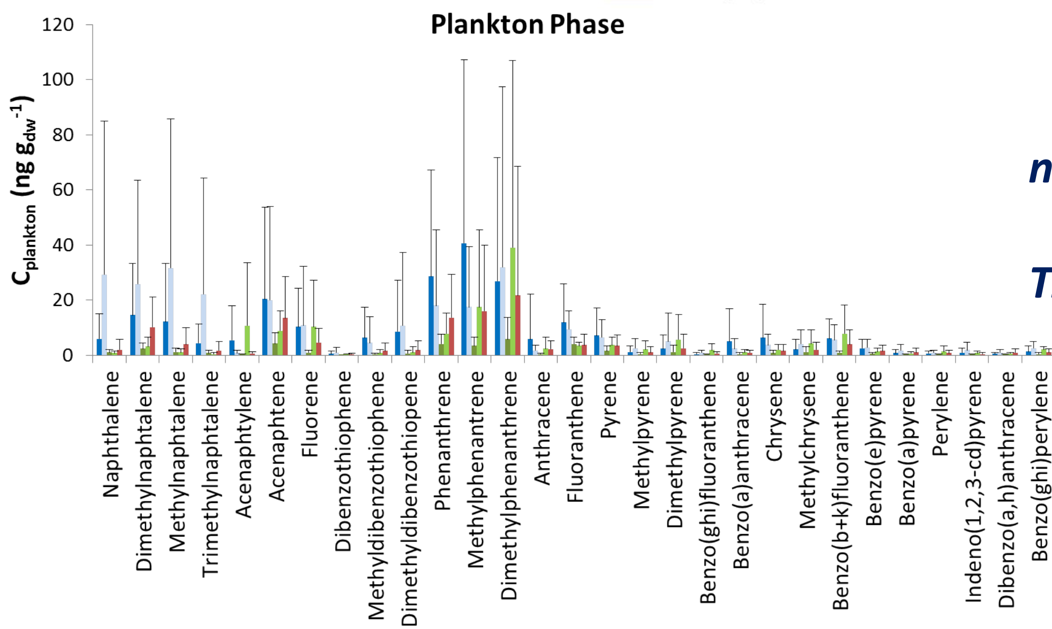


Environmental fate of SALCs and PAHs



PAHs in Oceanic Plankton

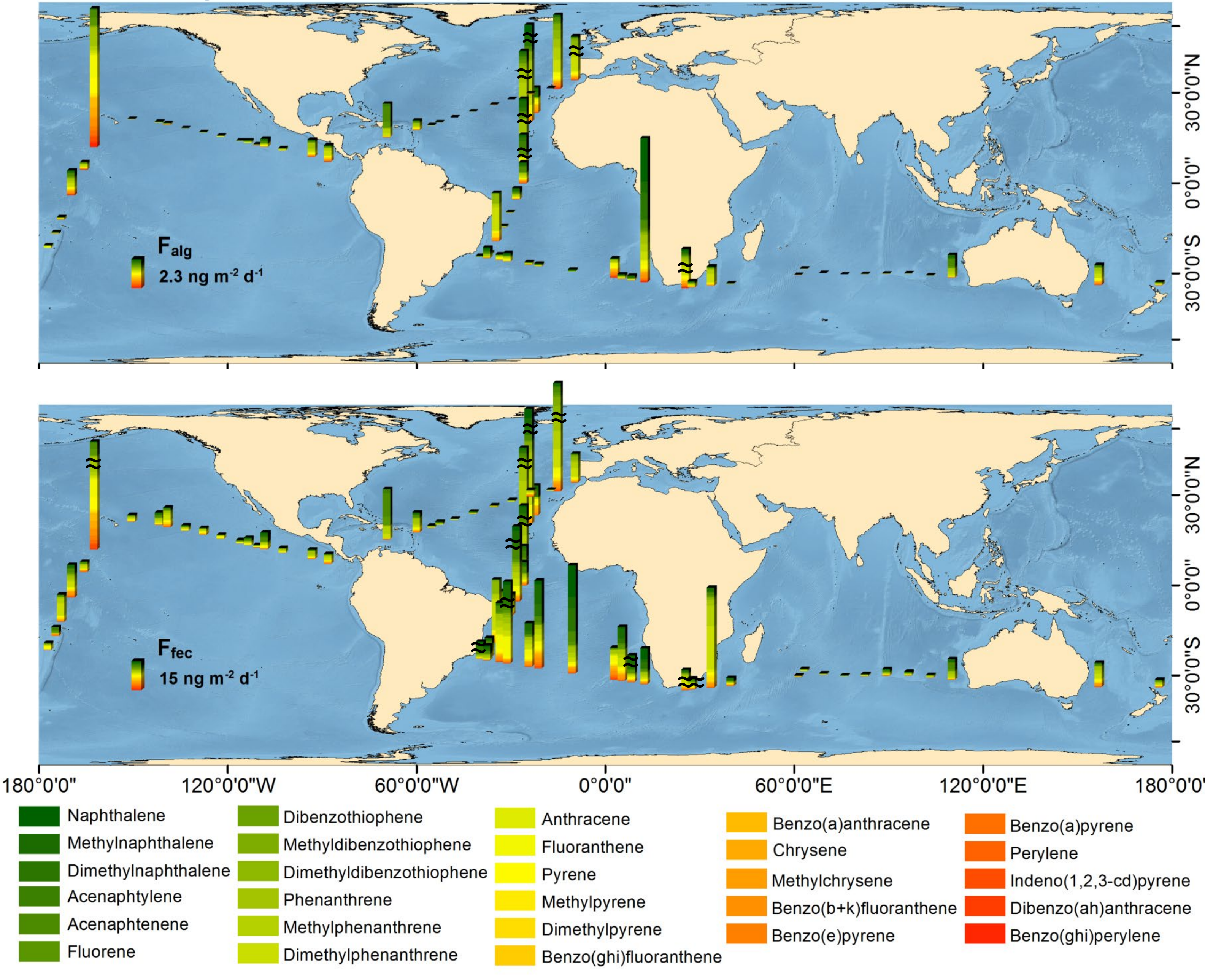




n=70

Trophic Level: 1.2-1.8

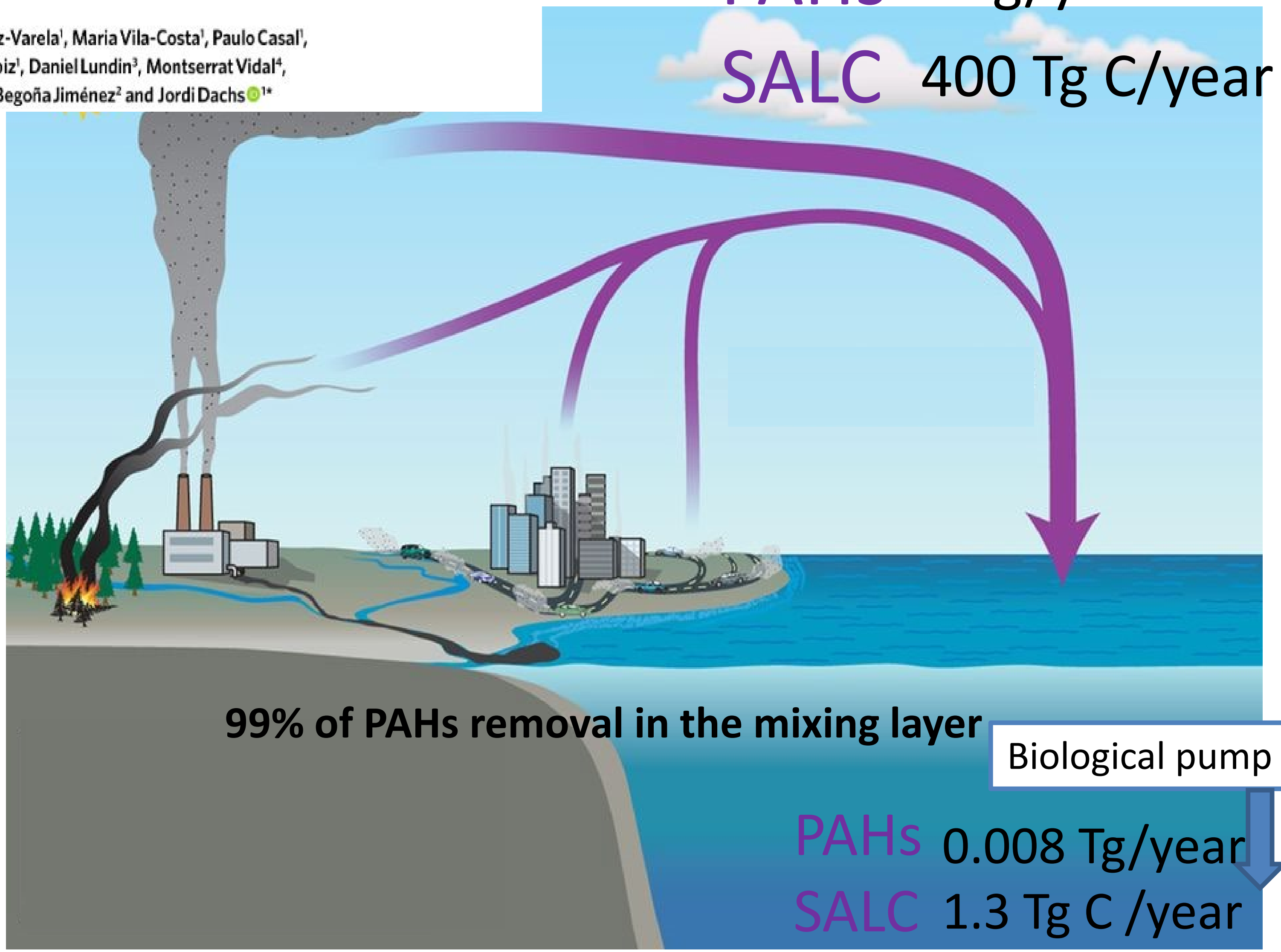
The Biological Pump for PAHs



nature geoscience
ARTICLES
https://doi.org/10.1038/s41561-018-0285-3

Biodegradation as an important sink of aromatic hydrocarbons in the oceans

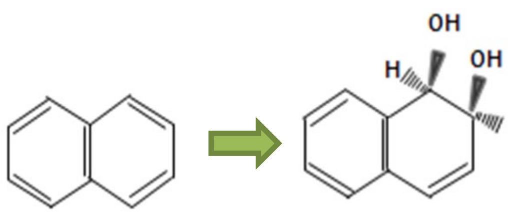
Belén González-Gaya[1,2], Alicia Martínez-Varela[1], Maria Vila-Costa[1], Paulo Casal[1], Elena Cerro-Gálvez[1], Naiara Berrojalbiz[1], Daniel Lundin[3], Montserrat Vidal[4], Carmen Mompeán[5], Antonio Bode[5], Begoña Jiménez[2] and Jordi Dachs[1*]

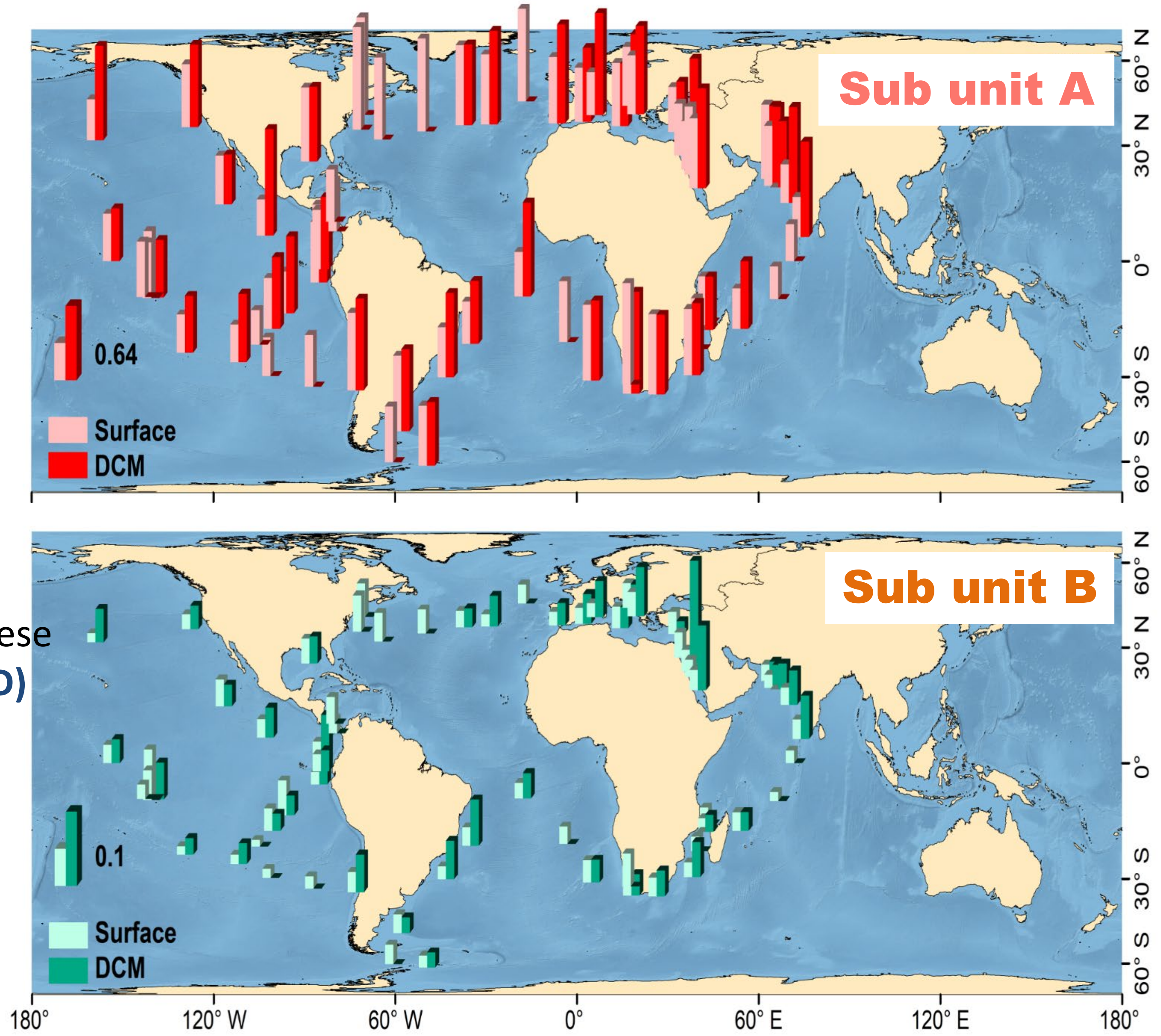


nature geoscience
ARTICLES
https://doi.org/10.1038/s41561-018-0285-3

Biodegradation as an important sink of aromatic hydrocarbons in the oceans

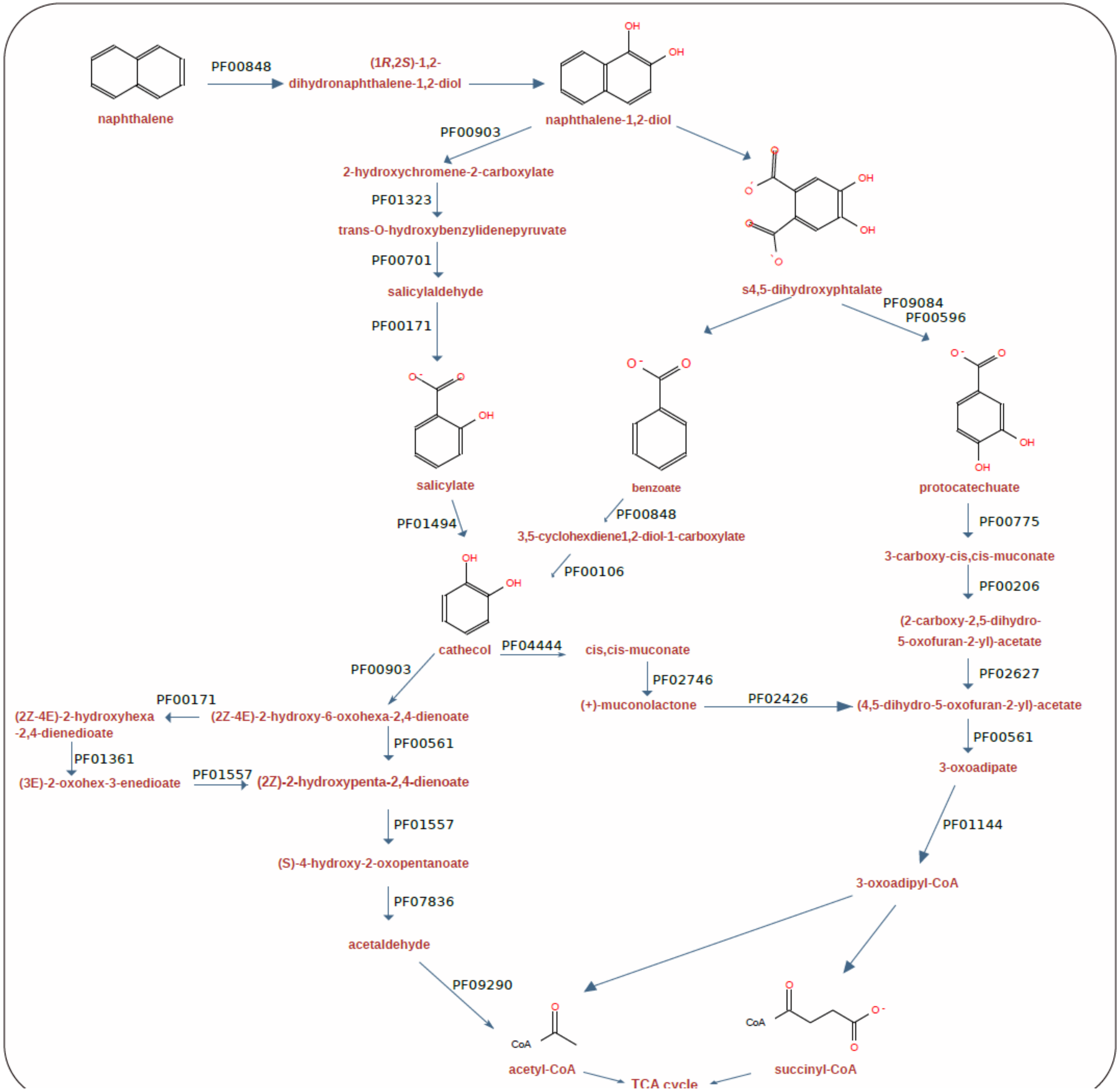
RHD abundance





Ring-hydroxylating dioxyganese Alpha and Beta subunit (**RHD**)

Marker genes suitable for molecular environmental diagnostics of hydrocarbon pollution in marine systems



Conclusions

- PAHs and other aromatic-like compounds are ubiquitous in the global oceanic atmosphere and water column.

- The main input of PAHs to the global ocean is through atmospheric deposition from the gas phase.

- There are large pools and fluxes of semivolatile organic compounds, largely uncharacterized, that could play an important role on the carbon cycle, and other environmental relevant processes.

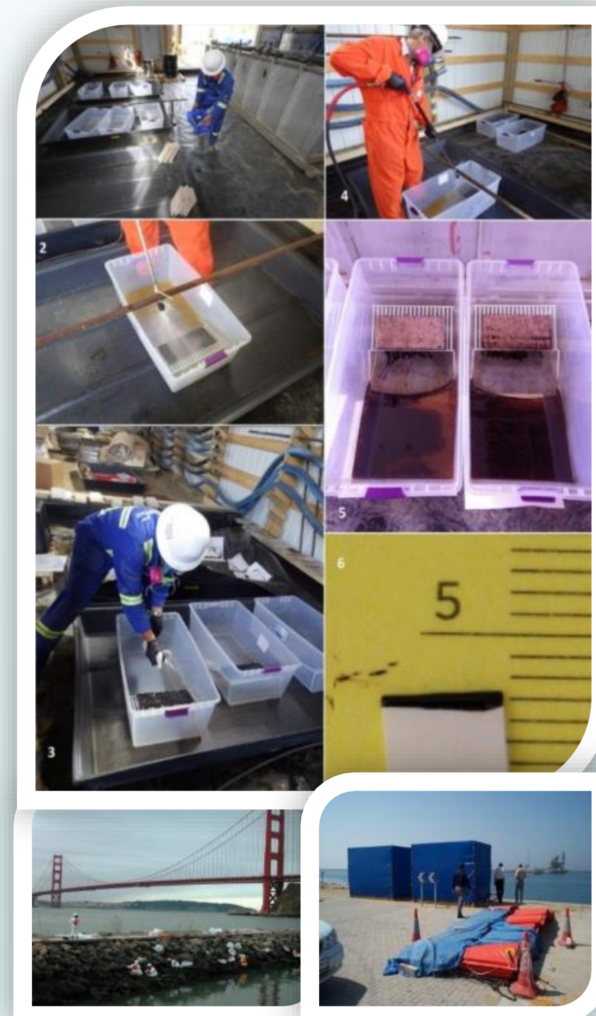
- These results imply large sources from land.

- 99% of the semivolatile aromatic and aliphatic hydrocarbons entering the ocean are degraded in the photic zone.

Acknowledgments

Work funded by:

- Spanish Government through various projects
- Consejo Superior de Investigaciones Científicas (CSIC)
- BBVA Foundation



Oil in the Sea

Natural Resource Damage Assessment in the United States

Greg Challenger, M.S.
President, Marine Scientist, Polaris Applied Sciences, Inc.
2021

Pollution Assessment and NRDA in the U.S.

Trends in Pollution Assessment

Successes and Challenges

The views expressed are those of Mr, Challenger and not meant as a comprehensive understanding of the NRDA process and all successes and challenges.

OIL SPILLS AND VESSEL GROUNDINGS IN CORAL IN THE UNITED STATES

Oil Pollution Act of 1990 (OPA), Marine Sanctuaries Act, National Parks Act

OPA - "*discharge or threat of discharge*"

Cost of restoring, replacing or requiring equivalent services pending full recovery.

U.S. SPILL EXPOSURES

- Cleanup and Reinstatement
- Third Party Claims
- Long Term Liabilities
- Penalties, Criminal Liabilities
- Cost of Environmental Assessment
- Lost Use - Natural Resource Damages

Technically Supportable Assessment

Federal Register / Vol. 61, No. 4 / Friday, January 5, 1996 / Rules and Regulations, Page **450-451**

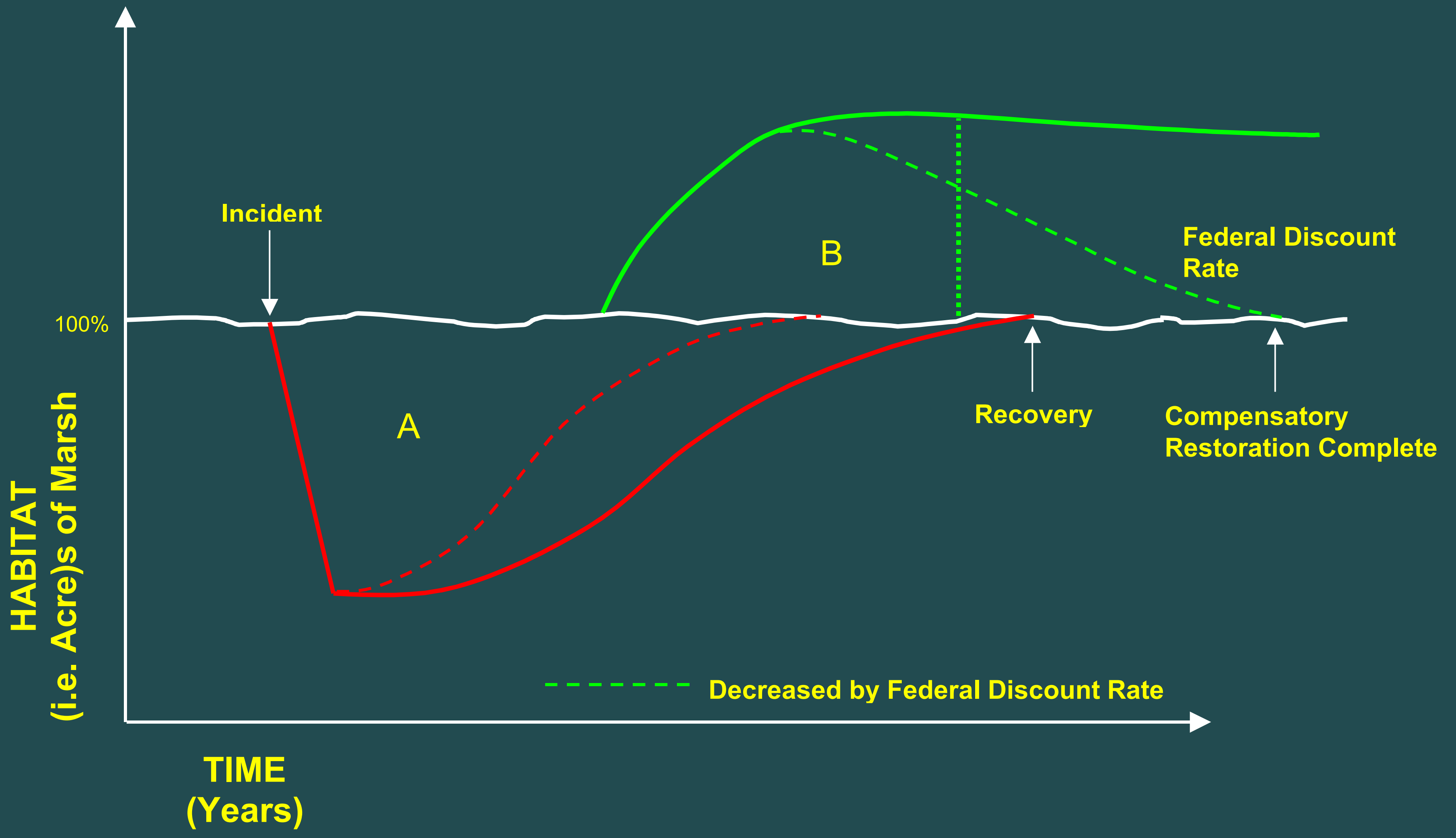
Exposure > Pathway > Injury

observable or measurable adverse change in a natural resource or service

OIL POLLUTION ACT OF 1990
Section 1006

Measure of Damages.—

1. In General. – The measure of natural resource damages under section 1002 (b)(s)(A) is –
   a) The cost of restoring, rehabilitating, replacing, or acquiring the equivalent of, the damaged natural resources;
   b) The diminution in value of those natural resources pending restoration; plus
   c) The reasonable cost of assessing those damages.



Incident
100%
A
B
Federal Discount
Rate
Recovery
Compensatory
Restoration Complete
Decreased by Federal Discount Rate
HABITAT
(i.e. Acre)s of Marsh
TIME
(Years)

NATURAL RESOURCE DAMAGE ASSESSMENT

Oil Pollution Act of 1990
Overview of Process

- PREASSESSMENT PHASE
  - Determine Jurisdiction
  - Determine Need to Conduct Restoration Planning
  - Whether Injury occurred

- RESTORATION PLANNING PHASE
  - Injury Assessment
    - Determine Injury
    - Quantify Injury
  - Restoration Selection
    - Develop Reasonable Range of Restoration Alternatives
    - Scale Restoration Alternatives
    - Select Preferred Restoration Alternative (s)
    - Develop Restoration Plan

- RESTORATION IMPLEMENTATION PHASE
  - Fund/Implement Restoration Plan

NRDA OPTIONS

Studies

Models

Assumptions from Past Case Studies

>>>>Negotiated Settlement

Rose Atoll, Jin Shiang Fa 1993

Trends
How should it work?
Early in the Process

- Collaborate
- Identify Resources At Risk
- Form Technical Working Groups (RAR-Oriented)
- What are the NRD questions?
- How will the data we seek get us to a restoration project?

Early Interaction between those responsible and the regulatory scientists

- Cooperative
- Collaborative
- Communication
- Transparency

Agreeing on data is easy.

Mega Borg, Gulf of Mexico 1990

What has been successful?

Early Interaction between agencies and with responsible party

Early Restoration

Experience of Practitioners

Restoration Project Success / Improvements

Early Interaction Benefits

- Trustees and Responsible Party operate with the same information
- Fewer unanswered questions
- Fewer disparate paths of assessment may develop
- Easier reconciliation of differences
- Agreeing on data is an important first step

Emergency Restoration/Early Restoration

“Emergency” restoration

Now called "Early Restoration"

More common today

$1B Early Restoration DWH GoM

Early restoration interactive map

Island Creation

Dune Restoration

Marsh Restoration

Oyster Reef

Human Use

Early Restoration Benefits

Environment –shortens the damage to the environment and lessens the loss

Shortens lost use (HEA discount rate)

Financial - Reduces future compensation needs.

ER Risks – Crediting or Scaling

Experience

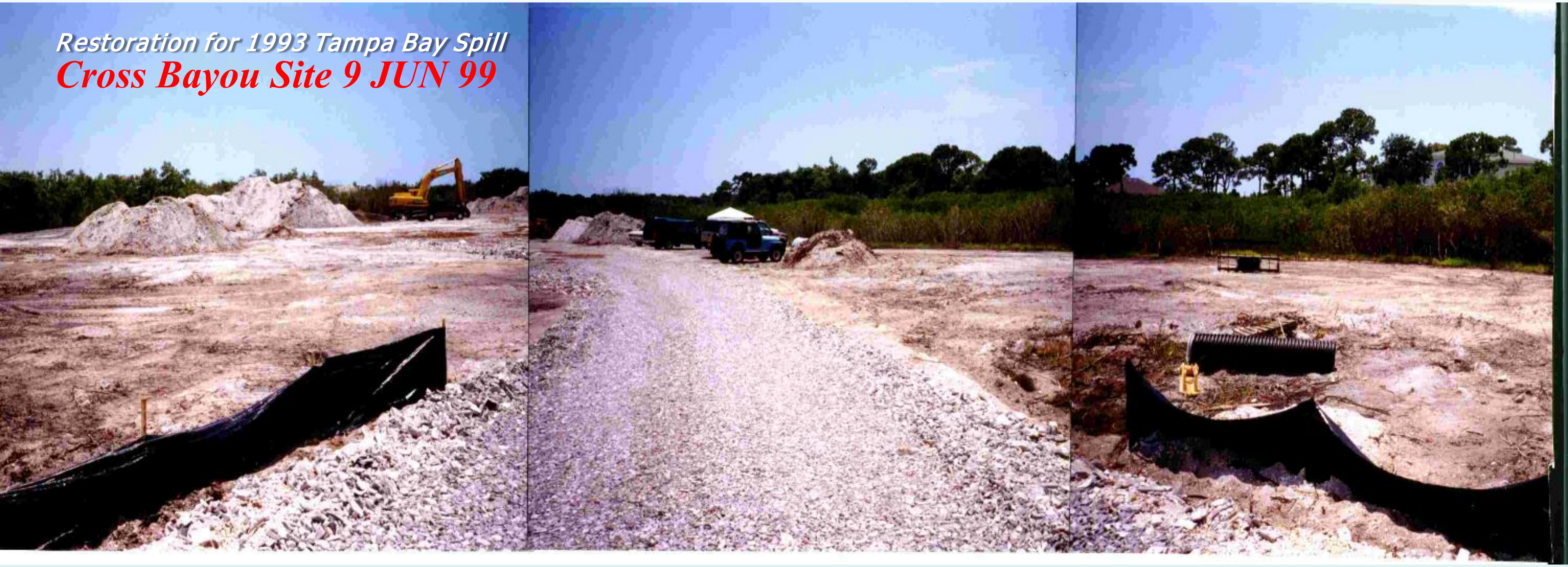
Case studies of the fate and effects for many oil types in many habitats are well known.

Expanded Research –(Regulatory, Industry, DWH)

Experience can tell us when further study may or may not produce a definitive result of adverse change resulting in agreement, or the end goal of restoration

Restoration Successes/Improvements

- North Cape Lobster V-Notch Program
- Aids to Navigation in FKNMS and Puerto Rico
- Island/Dune Reconstruction
- Bird Rehabilitation
- Coral Propagation


Restoration for 1993 Tampa Bay Spill
Cross Bayou Site 9 JUN 99


Cross Bayou Site 4 SEP 99
Restoration for 1993 Tampa Bay Spill

Cross Bayou Site 1 OCT 00

Cross Bayou Site 1 OCT 00

Challenges

Early Interaction

Early Restoration

Definition of Baseline

Scaling

NATURAL RESOURCE DAMAGE ASSESSMENT

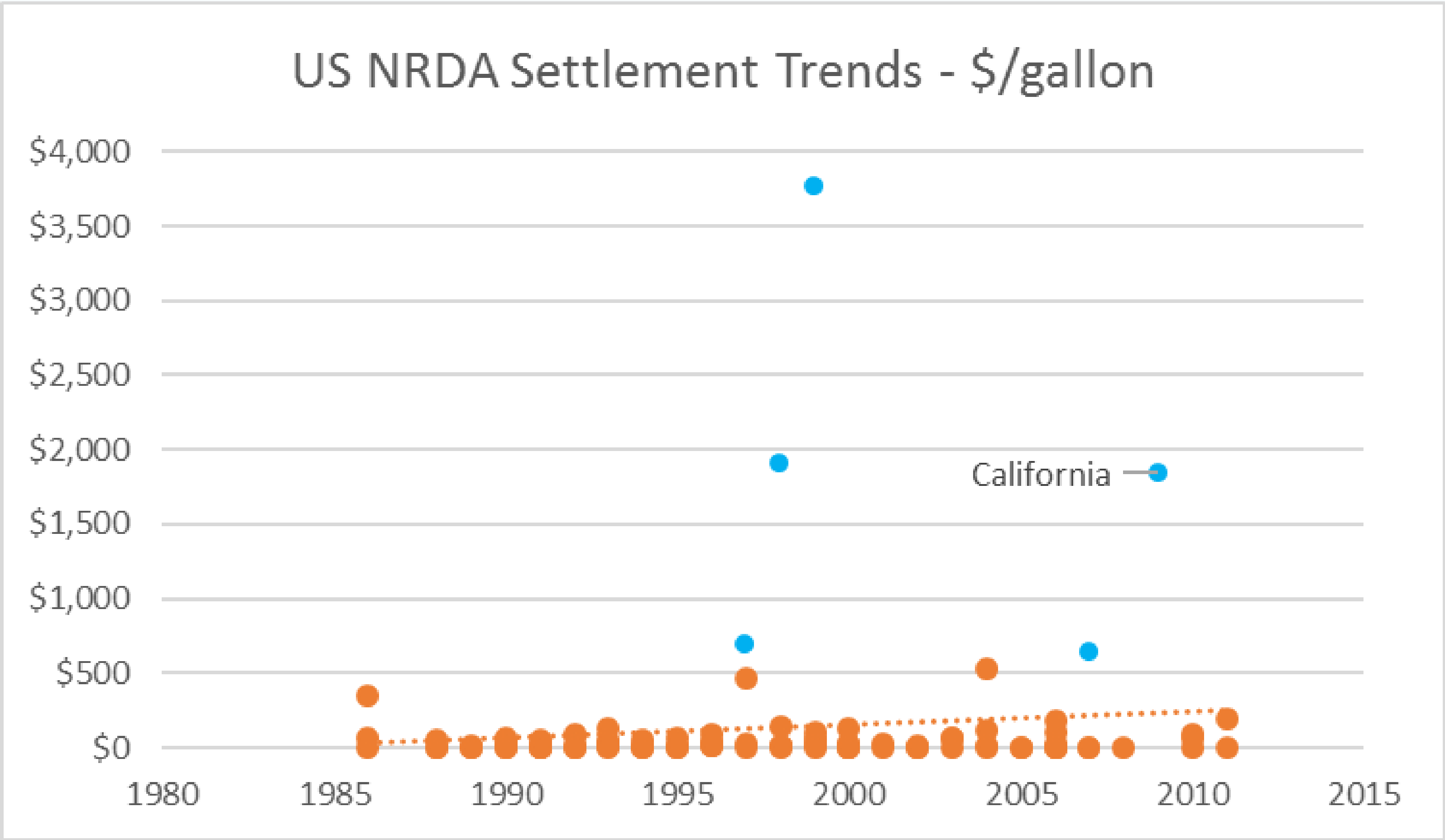
Oil Pollution Act of 1990

Overview of Process

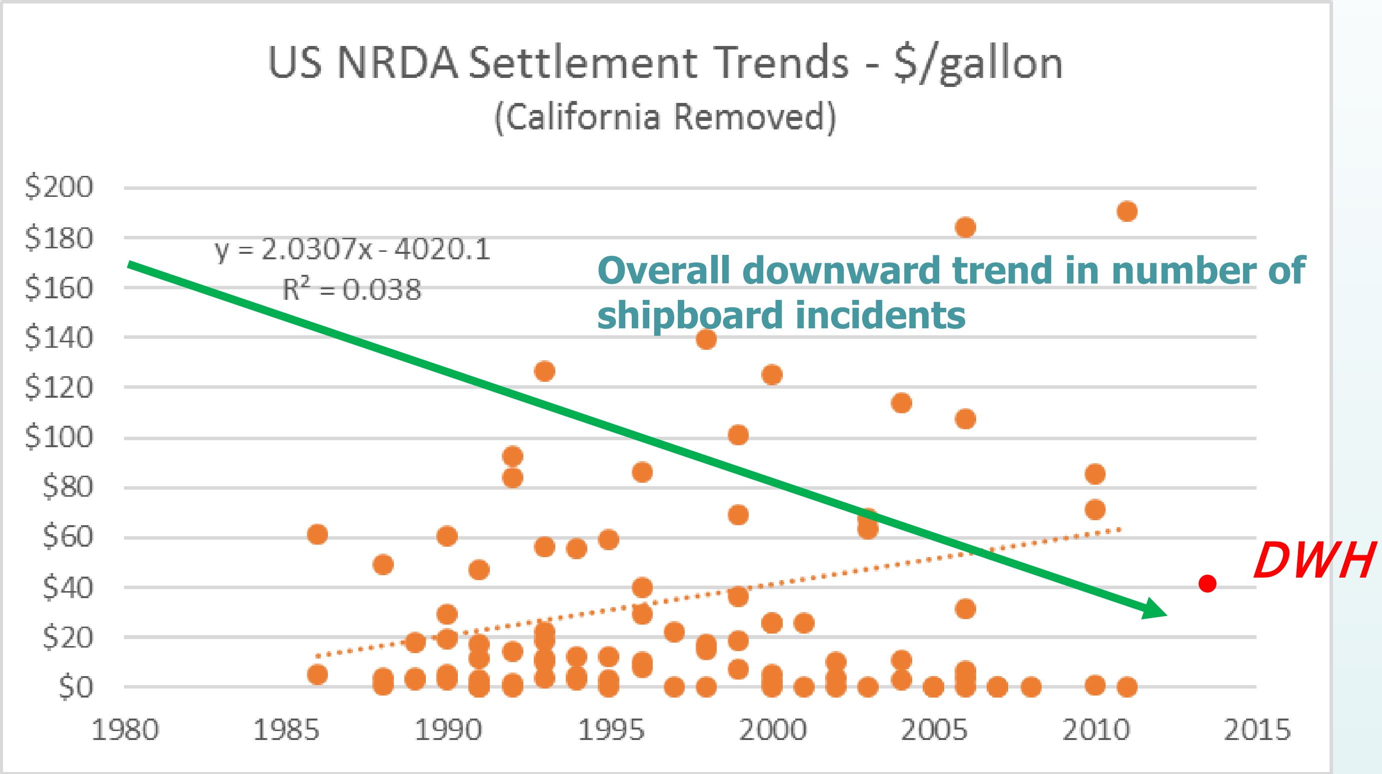
- *PREASSESSMENT PHASE*
  - *Determine Jurisdiction*
  - *Determine Need to Conduct Restoration Planning*
  - *Whether Injury occurred*

- *RESTORATION PLANNING PHASE*
  - *Injury Assessment*
    - *Determine Injury*
    - *Quantify Injury*
  - *Restoration Selection*
    - *Develop Reasonable Range of Restoration Alternatives*
    - *Scale Restoration Alternatives*
    - *Select Preferred Restoration Alternative (s)*
    - *Develop Restoration Plan*

- *RESTORATION IMPLEMENTATION PHASE*
  - *Fund/Implement Restoration Plan*



Dunford, R.W, Gmur S.G., Lynes, M.K., Challenger, G.E. and M.A. Dunford. 2019. Natural Resource Damages from Oil Spills in the United States. Environmental Claims Journal, Volume 31, 2019 - Issue 2



Approximate $40/gallon increase in average restoration-based settlement since 1990, but large variation and fewer shipping pollution accidents

NRDA Program Success

"$10.4 billion dollars to restore a wide variety of critical habitats and resources nationwide. Restoration funds have been used to restore wetlands, beaches, reefs, corals, and seagrasses and to open fish passage (e.g., dam removals) on many miles of streams. Funds have also been used to restore recreational uses like fishing, boating and swimming via boat ramps, fishing piers and improved access. In addition, protection and restoration have also been integrated into more than 500 waste site cleanups in order to reduce further injuries to natural resources and accelerate recovery."

https://darrp.noaa.gov/about-darrp/accomplishments

Questions

www.polarisappliedsciences.com

Greg E. Challenger

Please refuel
and be back by 1:30 pm EST!

Oil in the Sea IV: Inputs, Fates, and Effects

Committee Meeting 7 Agenda

March 11, 2021

OIL AND GAS OVERVIEW, OFFSHORE MEXICO

Porfirio Alvarez Torres, PhD
Executive Secretary
CiiMAR

OUTLINE

1. CiiMAR´s brief introduction
2. Oil and Gas production in Mexican waters
3. National spill response capacity
4. Spillage, sources/volumes
5. Spillage effects on ecosystem and coastal communities.

CIIMAR GOMC

Consorcio de Instituciones de Investigación Marina ... y del Caribe

CIIMAR GOMC

- ✓ **Established in November 2012**
- ✓ **Membership**
  - ✓ MEX: 34 academic and federal research institutes
  - ✓ US: over 120 academic, state and federal research organizations including: NASEM, NGI, LUMCON, GOMURC, GCOOS, US-IOOS, US-EPA, US-NOAA, US-BOEM, US-NASA, HRI, AMONG MANY OTHERS

CiiMAR aims to work with US Gulf of Mexico partners to:

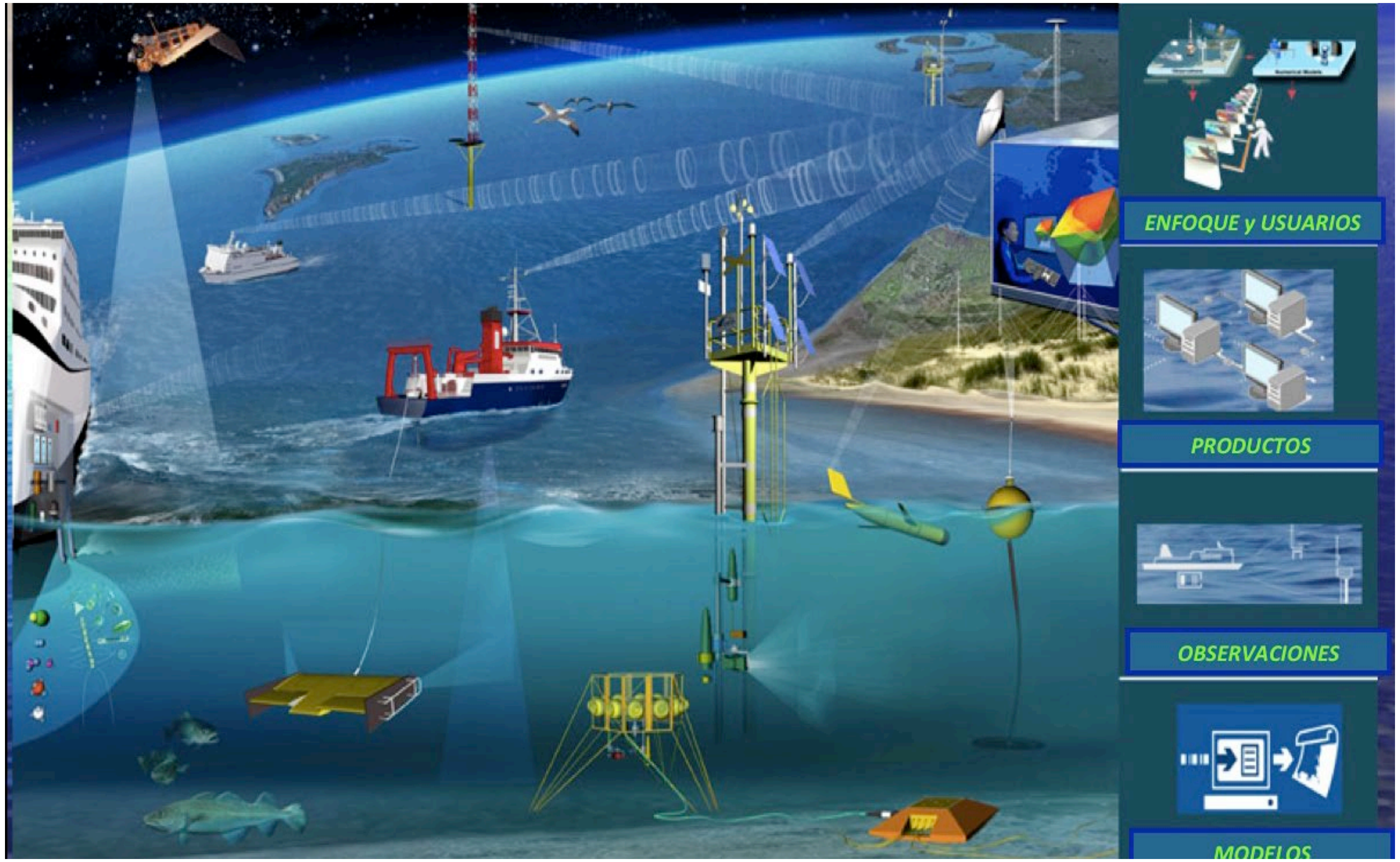
- ✓ **Enhance collaboration with U.S. academic, federal gov., NGOs & research institutions**
- ✓ **Strengthen joint research between the U.S. & Mexico, & Cuba**
- ✓ **Provide sound science for informed decision-making**
- ✓ **Strengthen higher education and technological development**
- ✓ **Strengthen national and international collaboration and exchange**
- ✓ **Consolidate public policies for regional benefit**




CIIMAR GOMC

Consorcio de Instituciones de Investigación Marina del Golfo de México y del Caribe

A model of coastal and ocean observing system that provides continuous information



- Natural hazards (met-ocean monitoring) / alerts
- Oil spill drift forecast
- Environment monitoring & evolutions forecast & management
- Renewable marine energies
- Turbidity / sedimentology
- Eutrophication, Harmful algal blooms, ..
- Hydrodynamics and biogeochemistry around islands (Indian and Pacific Oceans)

CIIMAR GOMC
Consorcio de Instituciones de Investigación Marina del Golfo de México y del Caribe

GULF OF MEXICO ALLIANCE

GOMURC
GULF OF MEXICO UNIVERSITY RESEARCH COLLABORATIVE

11th Regular session

Joint Session with the US Gulf of Mexico Alliance (GOMA) and the Gulf of Mexico Universities Research Collaborative (GOMURC)

Hosted by the University of Tabasco (UJAT) Villahermosa, Tabasco, April 2016

CIIMAR GOMC

Consorcio de Instituciones de Investigación Marina del Golfo de México y del Caribe

XII Ordinary and Joint Session with US- NASEM
Villahermosa Tabasco, 28th September 2016

Special Session with the Gulf Research Program US-NASEM

(National Academies of Science, Engineering and Medicine)

OUTLINE

1. CiiMAR´s brief introduction
2. Oil and Gas production in Mexican waters
3. National spill response capacity
4. Spillage, sources/volumes
5. Spillage effects on ecosystem and coastal communities.

ENERGY REFORM
December, 20th, 2013

- Publication in the Official Gazette of the "**Act to reform and add several provisions to the United States of Mexico's Constitution in energy matters**"

  - Opening of the market to **new hydrocarbons operators**
  - **New energy federal regulation structure**

Source: ASEA

MEXICO'S OIL & GAS INDUSTRY

PEMEX

2014

ENERGY REFORM

Monopoly

PEMEX

+

The opening up of the O&G sector

Round 0

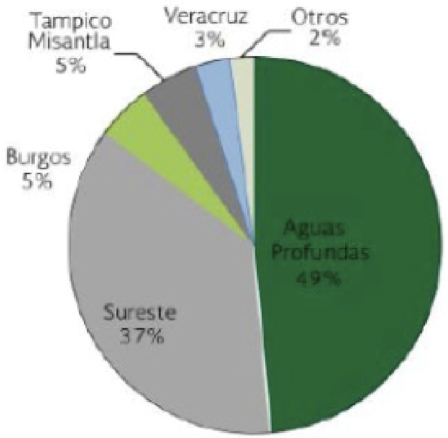
Round 1

L1 L2 L3 L4

TRION

Source: ASEA

Decrease of onshore and shallow water oil production in Mexico requires to explore toward deeper waters



Recursos prospectivos convencionales (MMMbpce)

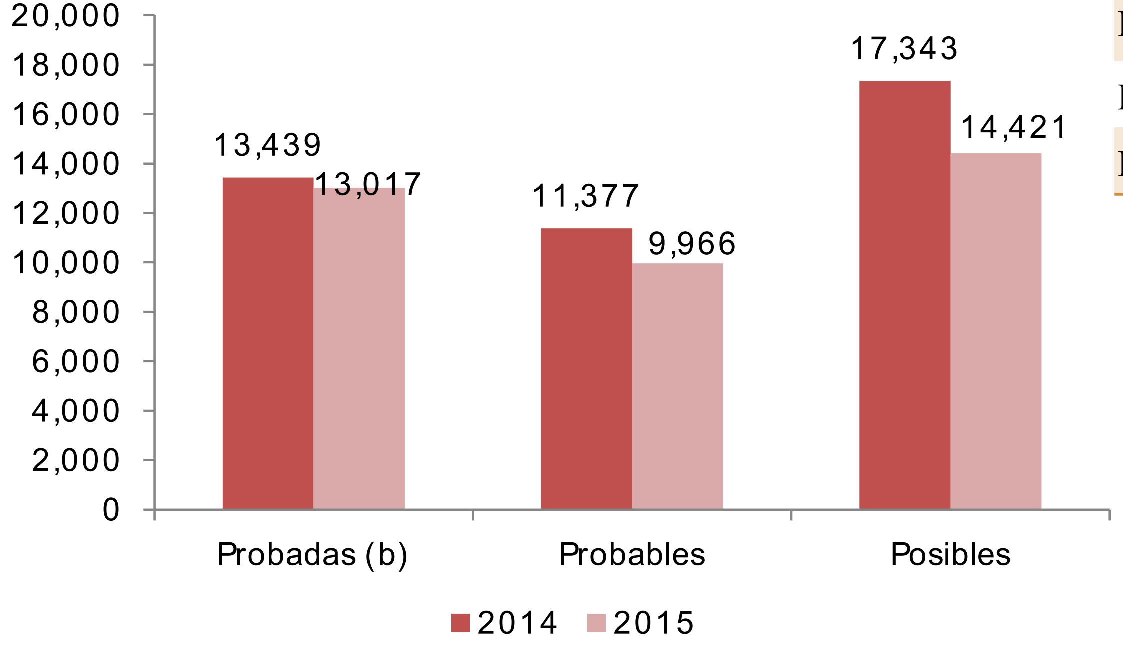
Cuenca	
Burgos	3.2
Aguas profundas en el Golfo de México	27.8
Sabinas	0.4
Sureste	15.8
Tampico-Misantla (ATG)	2.3
Veracruz	1.4
Plataforma de Yucatán	1.7
Total	52.6

49% of the Mexican prospective petroleum resources are located in deep waters (>500 m up to 3000 m)

Oil production by project (SENER, 2014)

HYDROCARBONS RESERVES (MMBPCE)

SOURCE: SENER, 2016



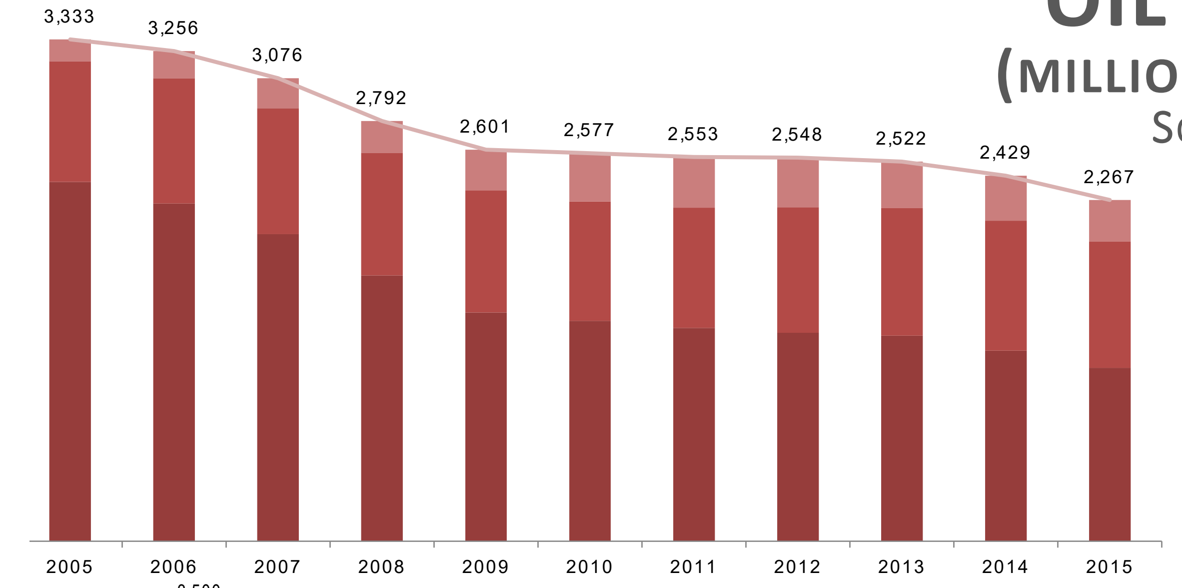
HYDROCARBON RESERVES

AL PRIMERO DE ENERO DE CADA AÑO

	2003	2013	2014	2015
TOTAL	**50,032**	**44,530**	**42,158**	**37,404**
PROVEN (B)	20,077	13,868	13,439	13,017
PROBABLY	16,965	12,306	11,377	9,966
POSSIBLY	12,990	18,356	17,343	14,421

DESPITE THE FACT THE INVESTMENT IN EXPLORATION INCREASED IN THE LAST TEN YEARS, THE OIL RESERVES ARE LESS THAN EXPECTED

OIL PRODUCTION
(MILLION OF BARRELS PER DAY)
SOURCE: SENER, 2016

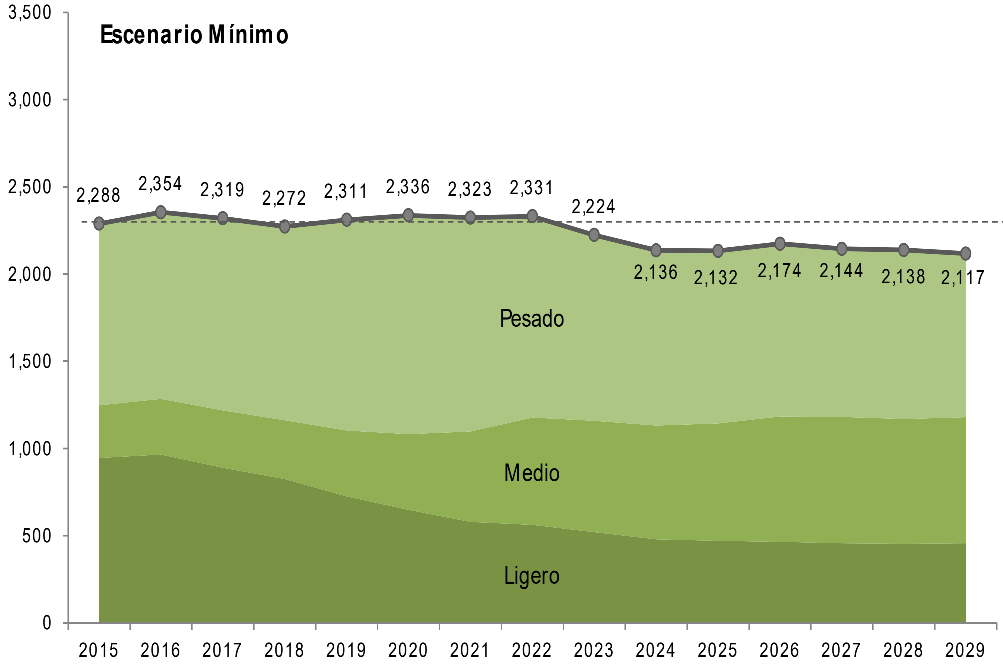


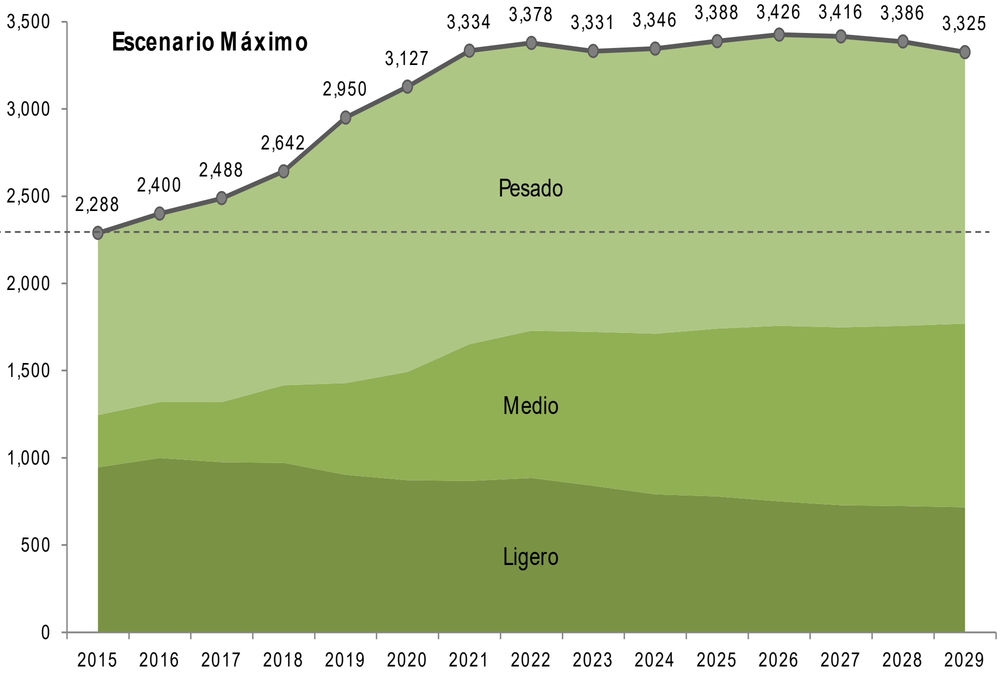
SUPERLIGERO

LIGERO

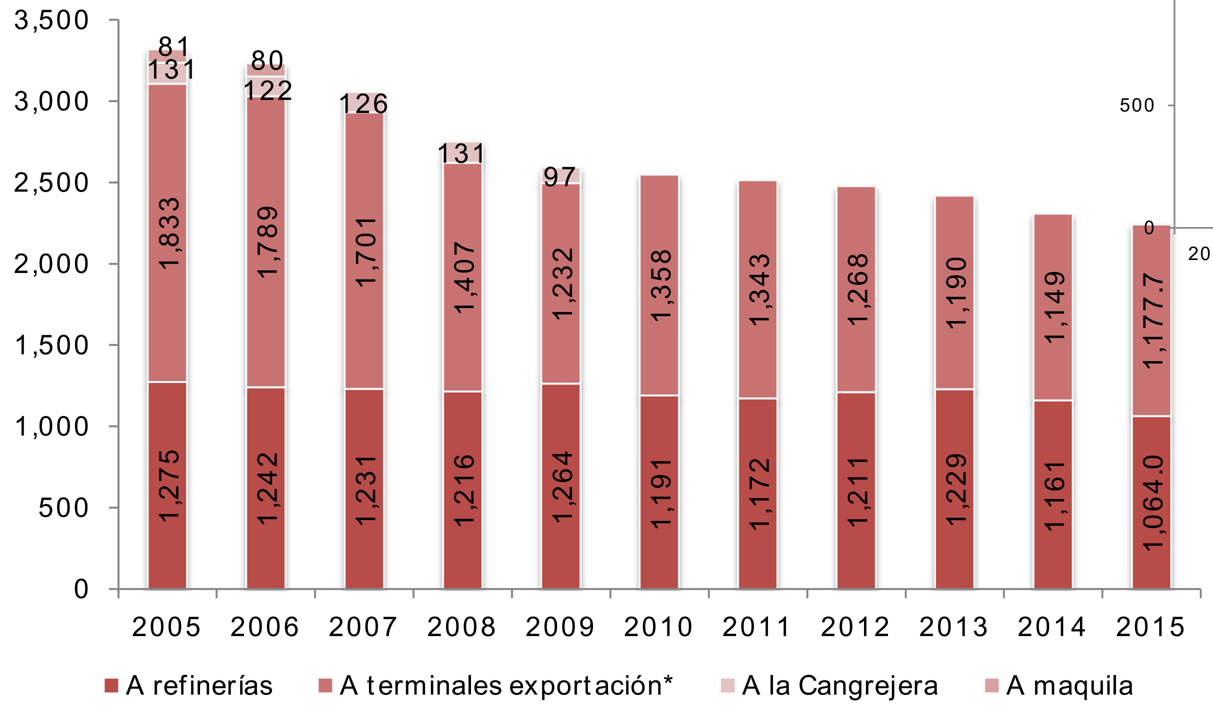
PESADO

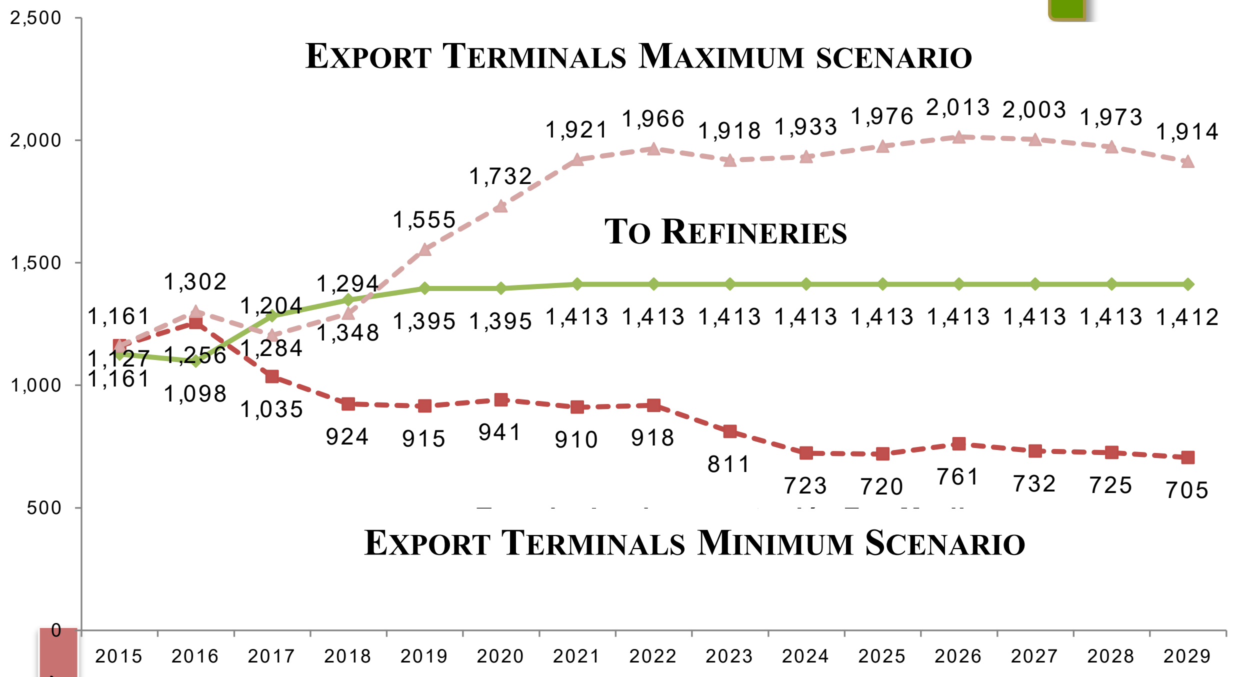
OIL PRODUCTION REDUCTION HAS BEEN ASSOCIATED TO THE CANTARELL REGION REDUCED PRODUCTION





OIL DISTRIBUTION (MBD). SOURCE: SENER, 2016





CURRENT OFFSHORE ACTIVITIES IN THE MEXICAN SIDE OF THE GULF OF MEXICO

- Around 350 offshore platforms
- 400-450 satellite platforms
- 15-20 processing centers
- 400-450 submarine pipelines, representing around 3,000-3,500 km

Source: ASEA

ROUNDS & TENDERS
Offshore

- Round 1: 3 tenders for contracts of Hydrocarbons E&P in shallow (2) and deep waters (1) in the Gulf of Mexico.
- 29 tendered areas / 12 adjudicated areas (41%)

Source: ASEA

FIVE-YEAR TENDERING PLAN FOR HYDROCARBON EXPLORATION AND PRODUCTION 2015-2019

Tenders for offshore resources EXPLORATION & PRODUCTION

Category	Number of areas to be tendered	Surface (km^2)
Deep waters	33	122,387.2
Shallow waters	56	44,657.3
Total	89	167,044.5

Source: ASEA

Pemex: Crude oil production by comprehensive asset

	2015	2016	2017	2018	2019
	(Mbd)				
Total	**2,267**	**2,154**	**1,948**	**1,823**	**1,684**
Subdirección de Producción Región Marina Noreste	**1,126**	**1,082**	**1,035**	**1,036**	**1,002**
Activo de Producción Cantarell	273	216	177	161	159
Activo de Producción Ku-Maloob-Zaap	853	867	858	875	843
Subdirección de Producción Región Marina Suroeste	**634**	**619**	**549**	**475**	**383**
Activo de Producción Abkatun- Pol-Chuc	287	259	203	184	184
Activo de Producción Litoral de Tabasco	347	360	346	291	199
Subdirección de Producción Región Sur	**393**	**344**	**267**	**219**	**208**
Activo de Producción Macuspana-Muspac	59	47	31	24	26
Activo de Producción Samaria-Luna	145	127	100	87	82
Activo de Producción Bellota-Jujo	102	90	72	59	58
Activo de Producción Cinco Presidentes	88	80	63	51	41
Subdirección de Producción Región Norte	**113**	**109**	**98**	**92**	**91**
Activo de Producción Reynosa	-	-	-	3	3
Activo de Producción Poza Rica-Altamira	101	94	83	72	65
Activo de Producción Veracruz	12	15	15	18	22

A partir de noviembre de 2017 se reporta con la nueva estructura de PEP y con la fuente de información SIIP.
El Activo Integral Aceite Terciario del Golfo se incorpora al Activo Integral Poza Rica-Altamira y actualmente es el Bloque N02.
La suma de los parciales y los porcentajes de variación pudieran no coincidir debido al redondeo.

Source: PEMEX, 2019

Pemex crude process

Pemex Proceso de crudo	Del 1 de enero al 31 de diciembre de			
	2018	2019	Variación	
Proceso total (Mbd)	**612**	**592**	**-3.2%**	**(20)**
Crudo ligero	396	300	-24.2%	(96)
Crudo pesado	216	292	35.2%	76
Crudo ligero / proceso total	64.7%	50.7%	-21.7%	(14.0)
Crudo pesado / proceso total	35.3%	49.3%	39.7%	14.0
Capacidad utilizada de destilación primaria[1]	**37.3%**	**36.1%**	**-3.2%**	**(1.2)**

[1]Incluye reprocesos.
La suma de los parciales y los porcentajes de variación pudieran no coincidir debido al redondeo.

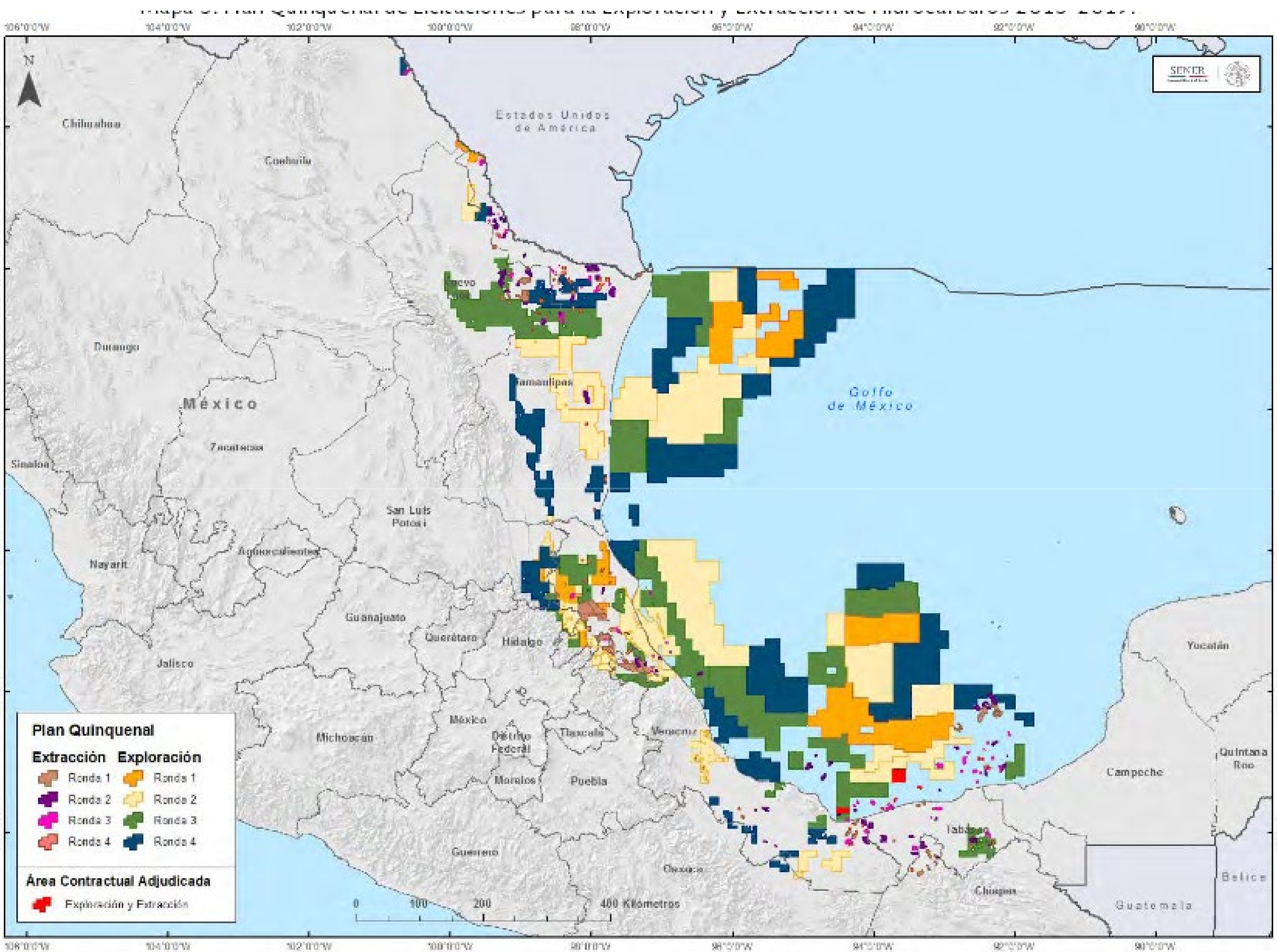
Pemex petroleum production

Pemex Producción de petrolíferos	Del 1 de enero al 31 de diciembre de			
	2018	2019	Variación	
Producción total (Mbd)[1]	**620**	**612**	**-1.3%**	**(8)**
Gasolinas automotrices[2]	198	190	-4.4%	(9)
Combustóleo	185	150	-19.1%	(35)
Diésel	117	130	11.5%	13
Gas licuado de petróleo (GLP)[2]	10	7	-28.7%	(3)
Turbosina	35	29	-16.3%	(6)
Otros[3]	75	106	41.6%	31

[1]Considera GLP de refinerías
[2]No Incluye transferencias
[3]Incluye gas seco gasóleos, aceite cíclico ligero, aeroflex, asfaltos, coque, extracto furfural, lubricantes y parafinas.
La suma de los parciales y los porcentajes de variación pudieran no coincidir debido al redondeo.

Source: PEMEX, 2019

FIVE-YEAR TENDERING PLAN FOR HYDROCARBON EXPLORATION AND PRODUCTION 2015-2019

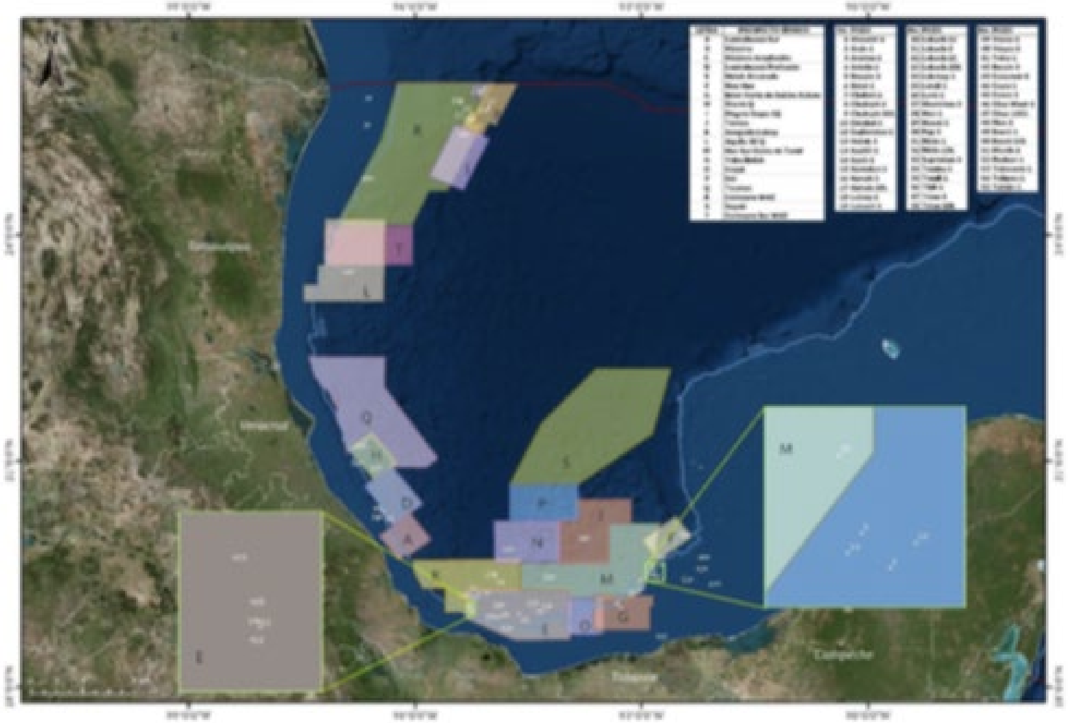


Source: ASEA

SOURCE: HYDROCARBON NATIONAL COMMISSION (CNH)

COMISIÓN NACIONAL DE HIDROCARBUROS

Data access round 1.4 deep waters



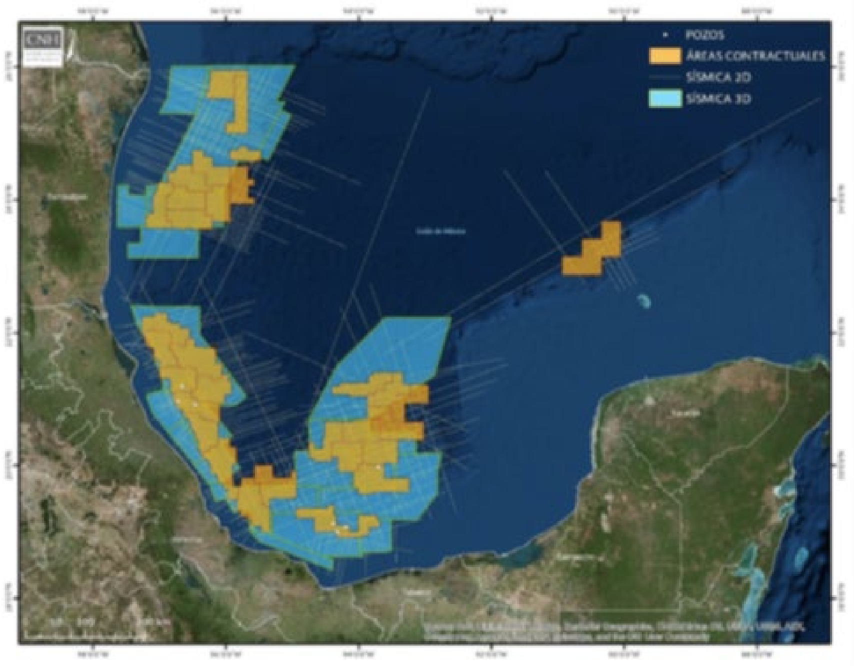
Pozos

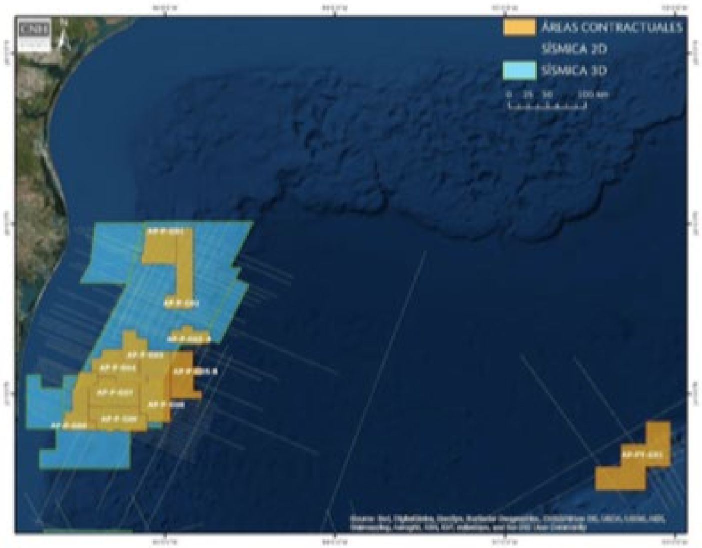
Clave	Nombre	No. de pozos
P1	Paquete de pozos # 1	41
P2	Paquete de pozos # 2	55

Data access round 2.4 deep waters

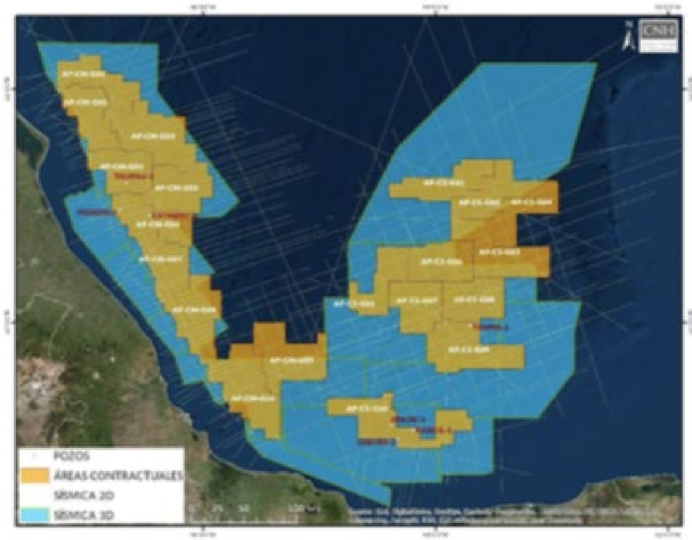
Map of contractual areas, 3D, 2D seismic and wells. Mexican mountain ranges and Salina Basin.

Mapa de áreas contractuales, sísmica 3D, 2D y pozos





Mapa de áreas contractuales, sísmica 3D, 2D y pozos
Zonas Cordilleras Mexicanas y Cuenca Salina

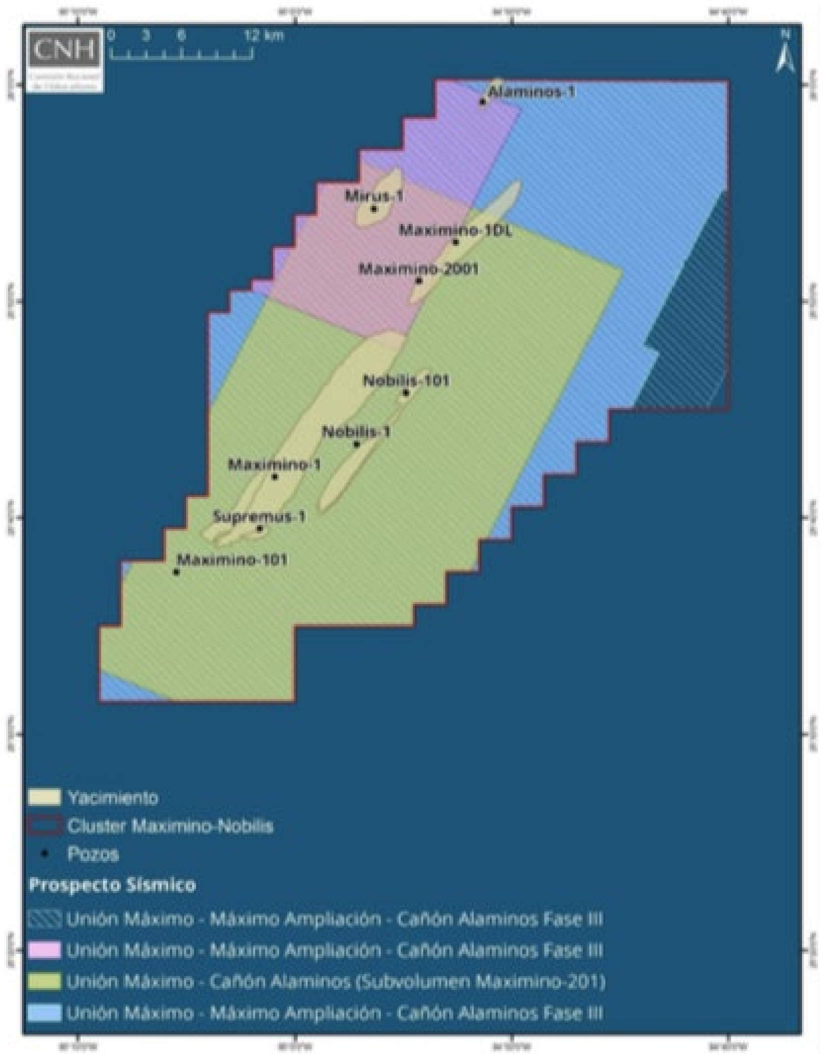


Data access Nobilis-Maximino deep waters

Pozos. Información de 9 pozos exploratorios:

#	Nombre	Año de perforación
1	ALAMINOS-1	2016
2	MAXIMINO-1	2013
3	MAXIMINO-101	2016
4	MAXIMINO-1DL	2015
5	MIRUS-1	2016
6	NOBILIS-1	2016
7	NOBILIS-101	2017
8	SUPREMUS-1	2012
9	MAXIMINO-2001	2017

Mapa del área contractual, sísmica 3D y pozos

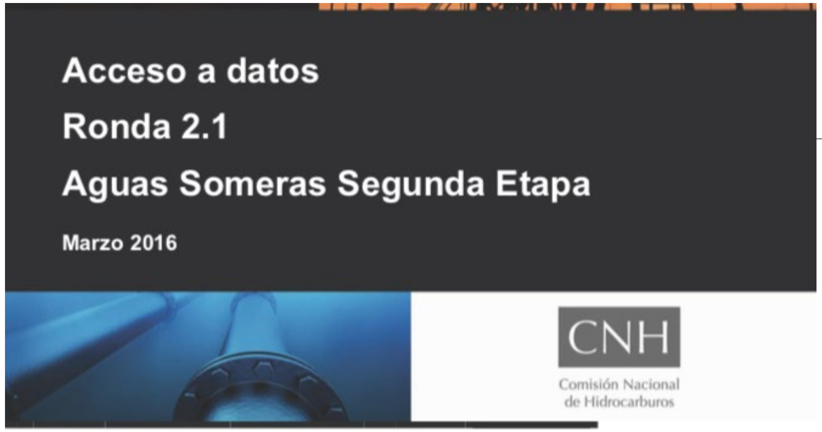


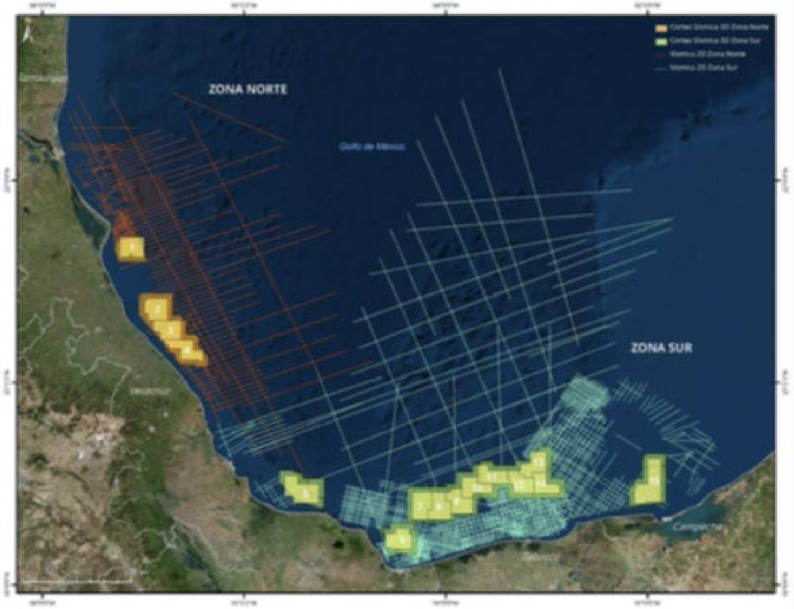
Access to data Shallow waters first stage

Pozos

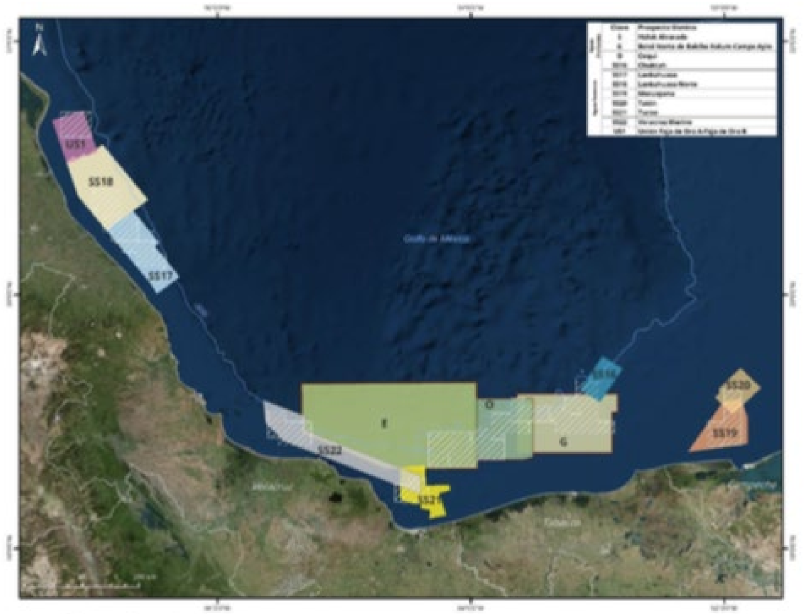
Clave	Nombre	No. de pozos
PS1	Paquete de pozos Ayatsil-Tekel-Utsil	9
PS2	Paquete de pozos Ek-Balam	75
PS3	Paquete de pozos Sinán-Bolontikú	49
PS4	Paquete de pozos Exploratorios	32

Access to data Round 2-1 shallow waters second stage



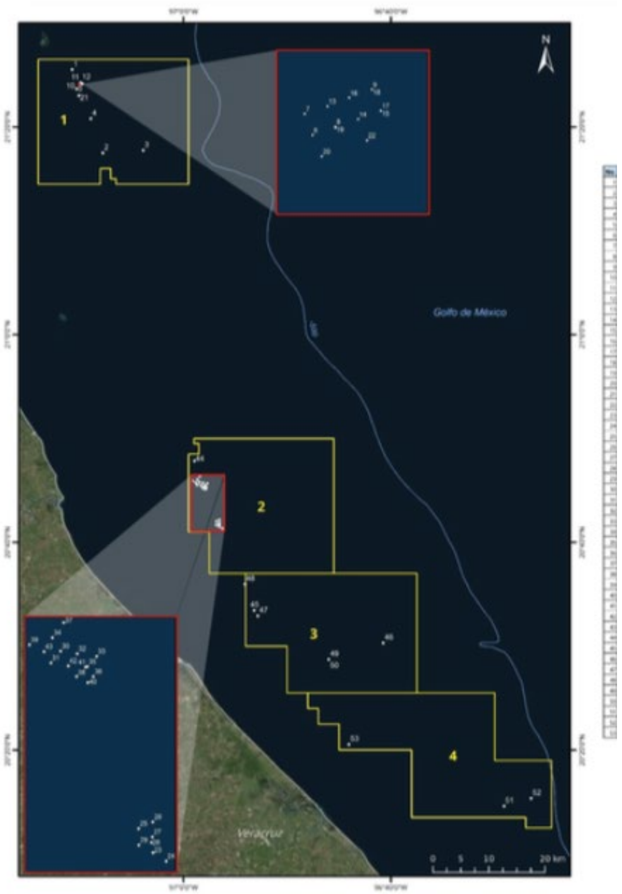


Estudios Sísmicos 2D



Estudios Sísmicos 3D

Los estudios pueden ser adquiridos con todas las versiones que lo integran o hacer un selección de versiones. Para conocer los detalles consulte las "Fichas técnicas" en la secció de *Especificaciones técnicas de la información*.



Access to data Round 2-1 shallow waters second stage

Wells

Pozos

Pozos Zona Norte (53 pozos)

Área contractual	Num.	Nombre
1	1	BACALAO-1
	2	BOQUERON-1
	3	CALIPSO-1
	4	HUACHINANGO-2
	5	TIBURON-1
	6	TIBURON-11
	7	TIBURON-12
	8	TIBURON-13
	9	TIBURON-14
	10	TIBURON-1A
	11	TIBURON-2
	12	TIBURON-2A
	13	TIBURON-2B
	14	TIBURON-3
	15	TIBURON-4
	16	TIBURON-6
	17	TIBURON-7
	18	TIBURON-8
	19	TIBURON-9
	20	TINTORERA-1
	21	TINTORERA-101
	22	TINTORERA-2
2	23	ESCUALO-12
	24	ESCUALO-14
	25	ESCUALO-16
	26	ESCUALO-2
	27	ESCUALO-4

Área contractual	Num.	Nombre
2	28	ESCUALO-6
	29	ESCUALO-8
	30	MORSA-10
	31	MORSA-12
	32	MORSA-14
	33	MORSA-16
	34	MORSA-18
	35	MORSA-2
	36	MORSA-20
	37	MORSA-24
	38	MORSA-26
	39	MORSA-28
	40	MORSA-32
	41	MORSA-4
	42	MORSA-6
	43	MORSA-8
	44	PARGO-2
3	45	CANGREJO-1
	46	CHIHUIX-1
	47	MEJILLON-1
	48	MERO-1
	49	PAMPANO-1A
	50	PAMPANO-1B
4	51	KOSNI-1
	52	KOSNI-101
	53	LANKAHUASA NORTE-1

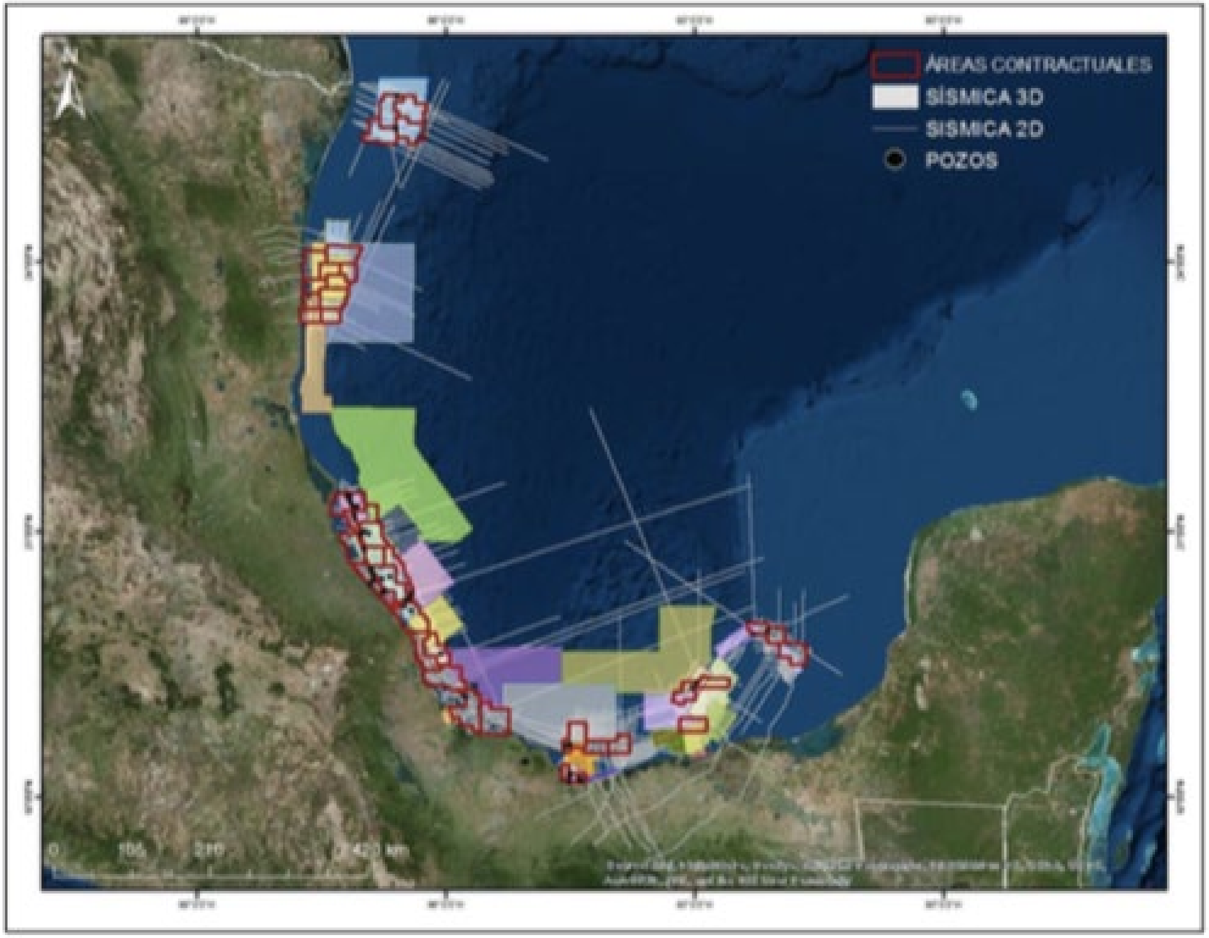
Área contractual	Num.	Nombre
Fuera	54	LAKACH-1
Fuera	55	LAKACH-2DL
6	56	TONATIUH-1
7	57	COX-1
12	58	BOLOL-1
	59	KEXUL-1
13	60	TIBIL-1
14	61	ACACH-1
	62	ACACH-1A
	63	XULUM-1

Área contractual	Num.	Nombre
14	64	XULUM-101
	65	XULUM-101A
15	66	CAAN-2169
	67	IKIM-1
	68	MALAH-1
	69	PECH-1
Fuera	70	PIXAN-1
15	71	SAMAL-1
	72	XOTEM-1

Access to data Round 3-1 shallow waters

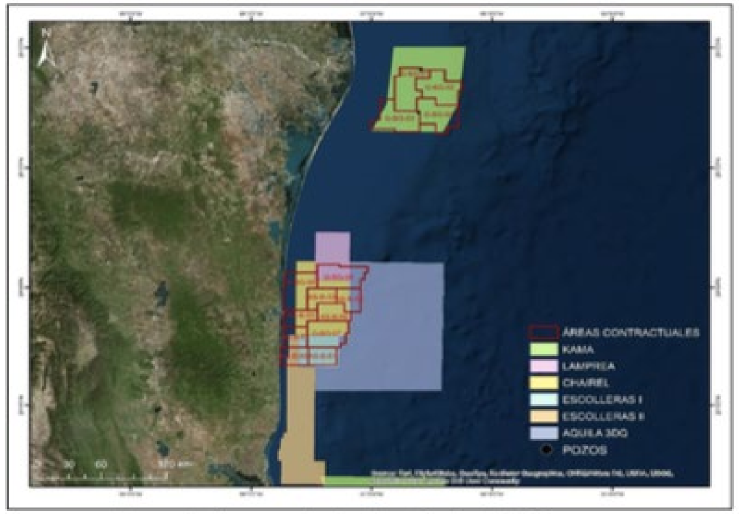
Map of contractual areas, 3D, 2D seismic and wells.

Mapa de áreas contractuales, sísmica 3D, 2D y pozos

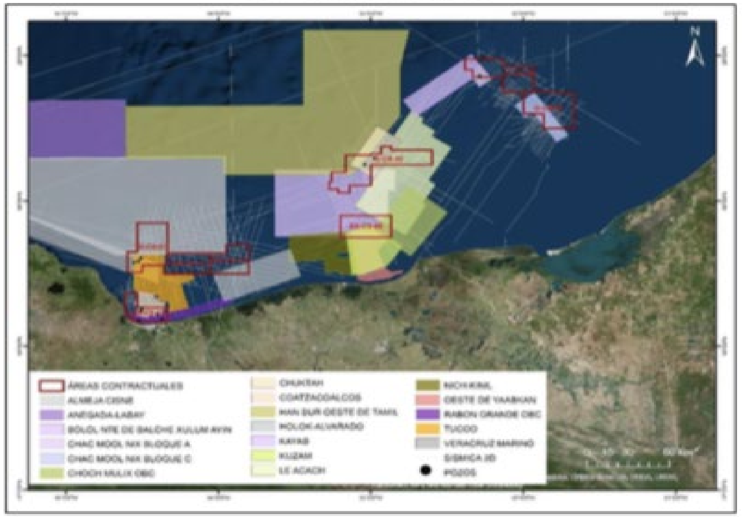


Access to data Round 3-1 shallow waters

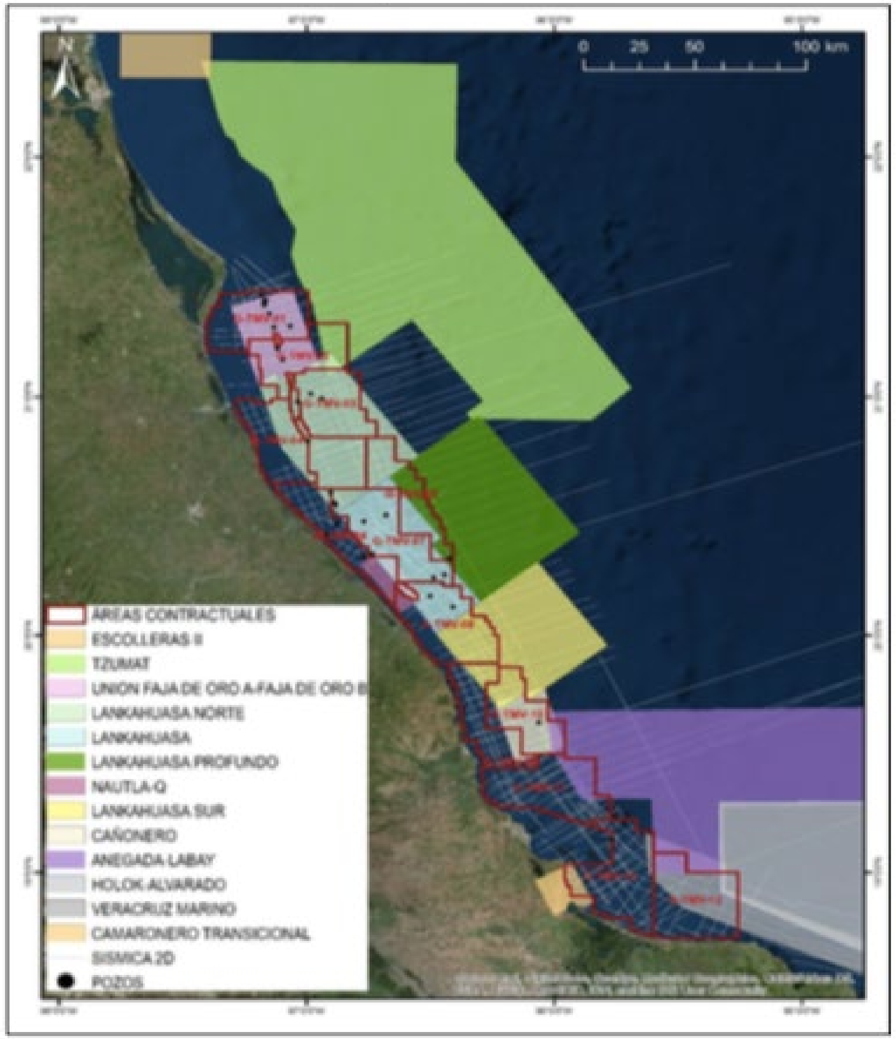
Map of contractual areas, 3D, 2D seismic and wells. Southeast basin area



Mapa de áreas contractuales, sísmica 3D, 2D y pozos
Zona Cuencas del Sureste

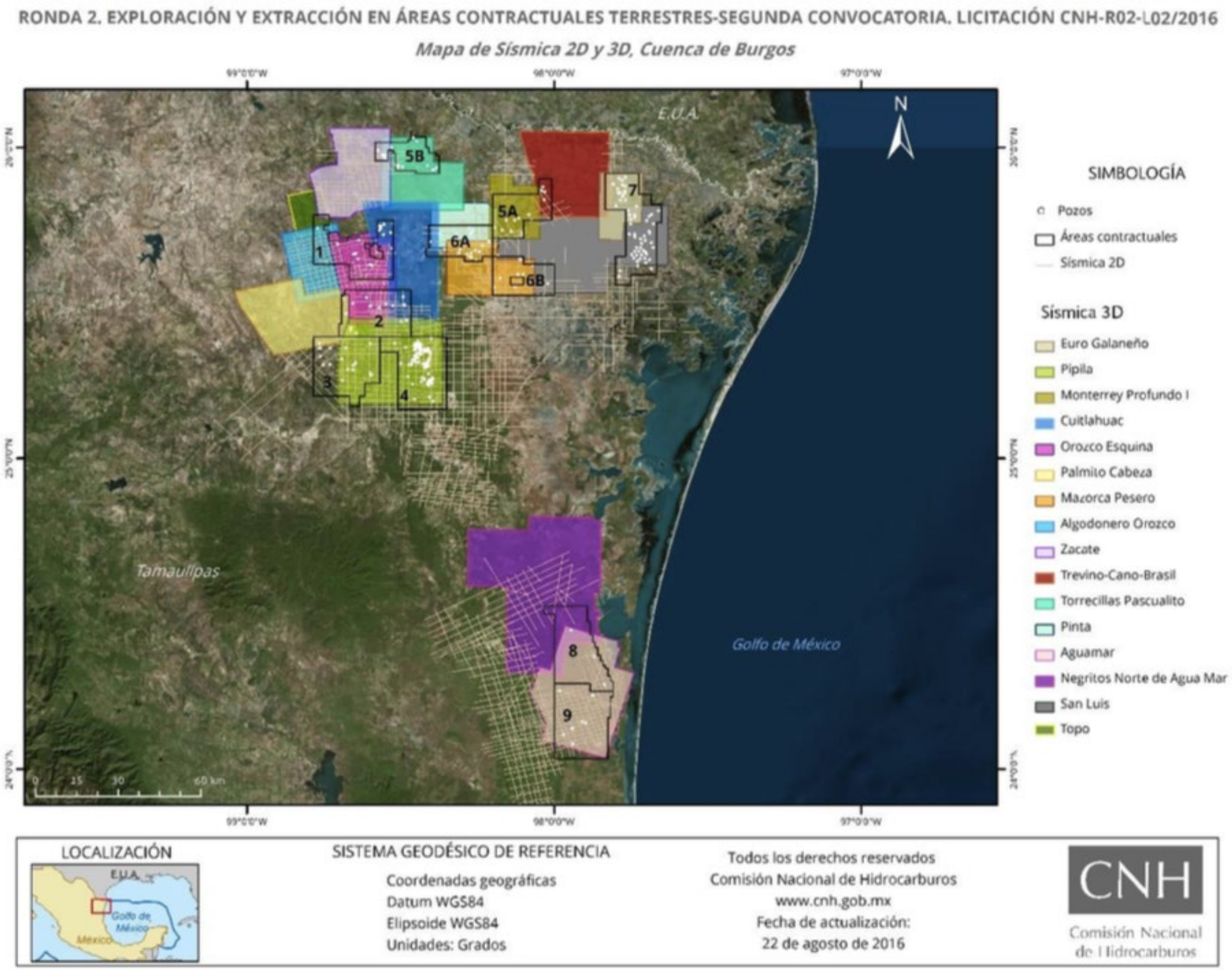


Zonas Tampico-Misantla-Veracruz



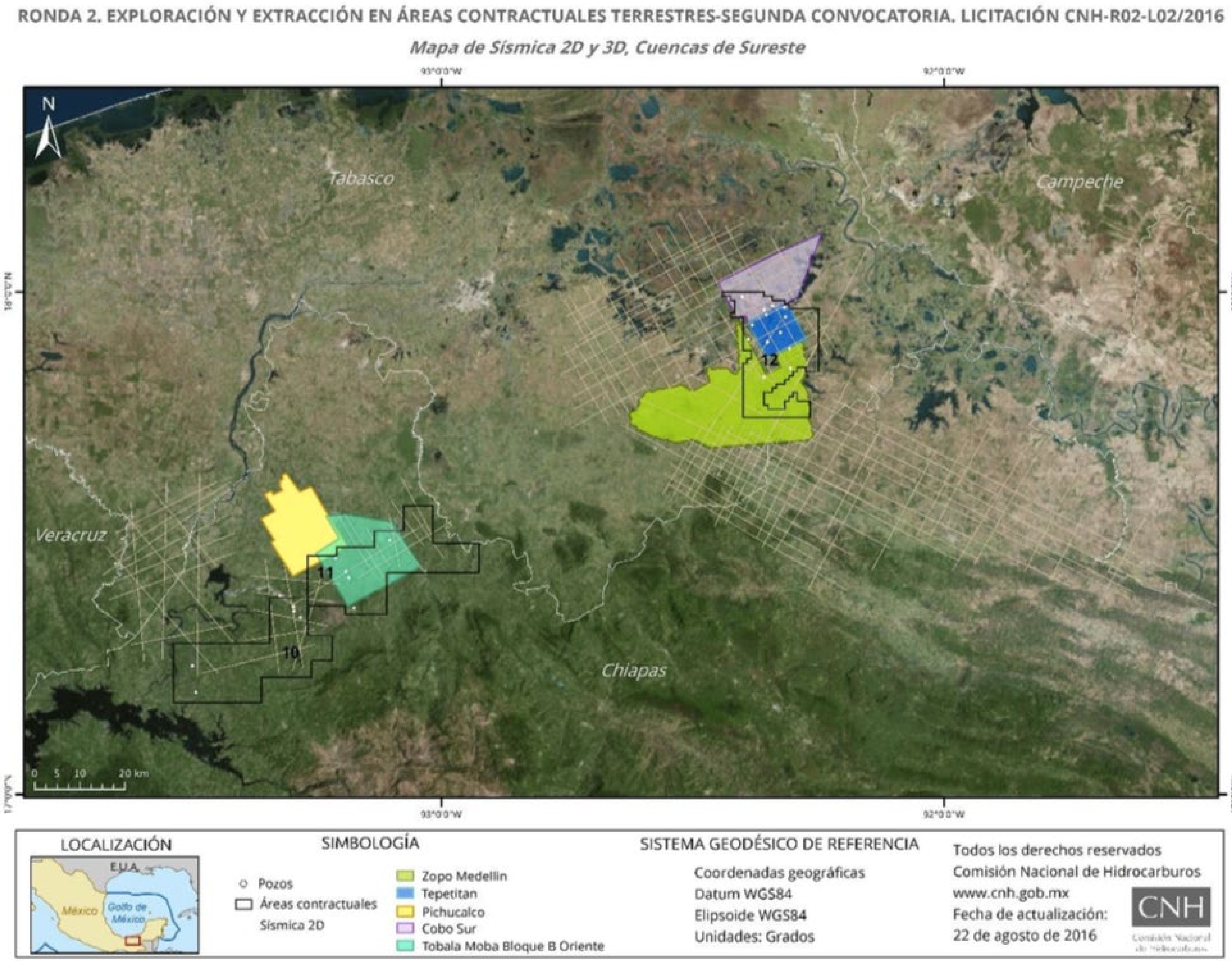
Access to data round 2.2 terrestrial first stage.

Map of contractual areas, 3D, 2D seismic and wells. Gas zone.



Access to data round 2.2 terrestrial first stage.

Map of contractual areas, 3D, 2D seismic and wells.



Access to data round 2.3 terrestrial second stage.

Map of contractual areas, 3D, 2D seismic and wells. North and south zone

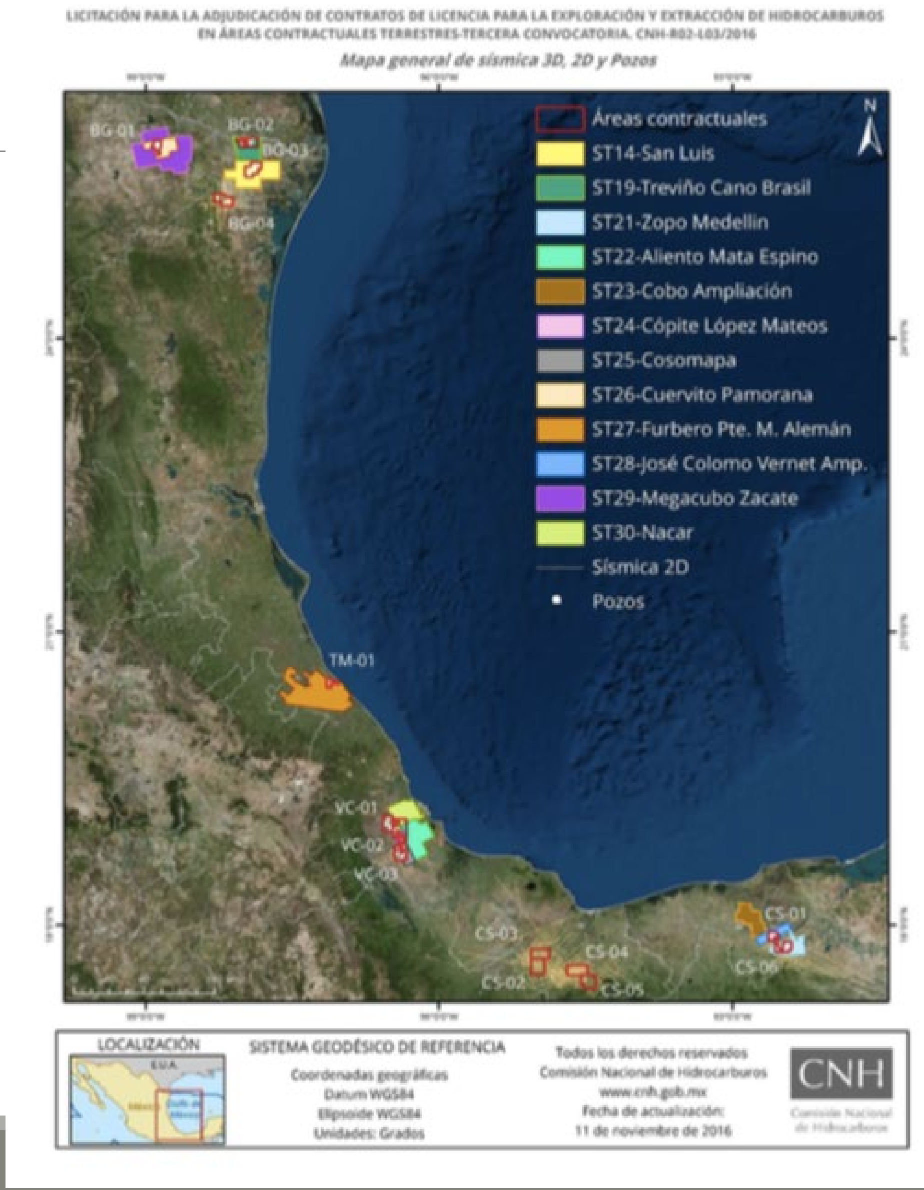
Mapa de paquetes con pozos, sísmica 2D y sísmica 3D cortada a las áreas, Zona Norte

Mapa de paquetes con pozos, sísmica 2D y sísmica 3D cortada a las áreas, Zona Sur

Mapa de áreas contractuales e información disponible

Access to data round 2.3 terrestrial second stage.

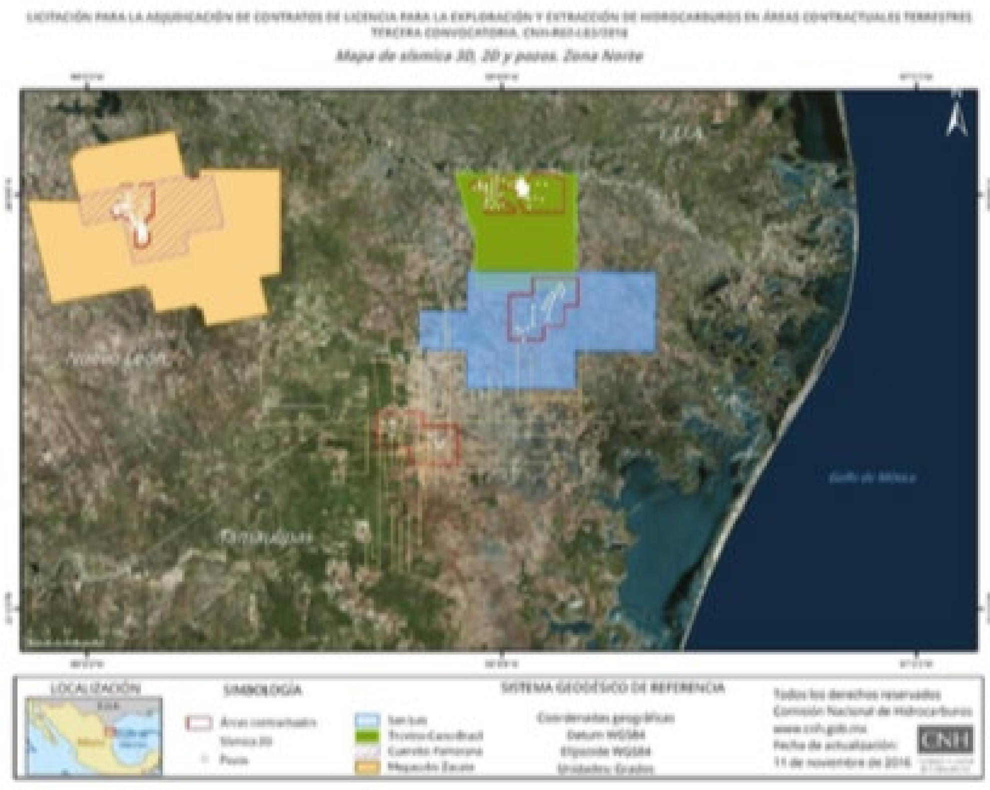
Map of contractual areas, 3D, 2D seismic and wells.



Access to data round 2.3 terrestrial second stage.

Map of contractual areas, 3D, 2D seismic and wells.

Símica 3D sin cortes, sísmica 2D y pozos, Zona Sur



Gas exploration and production

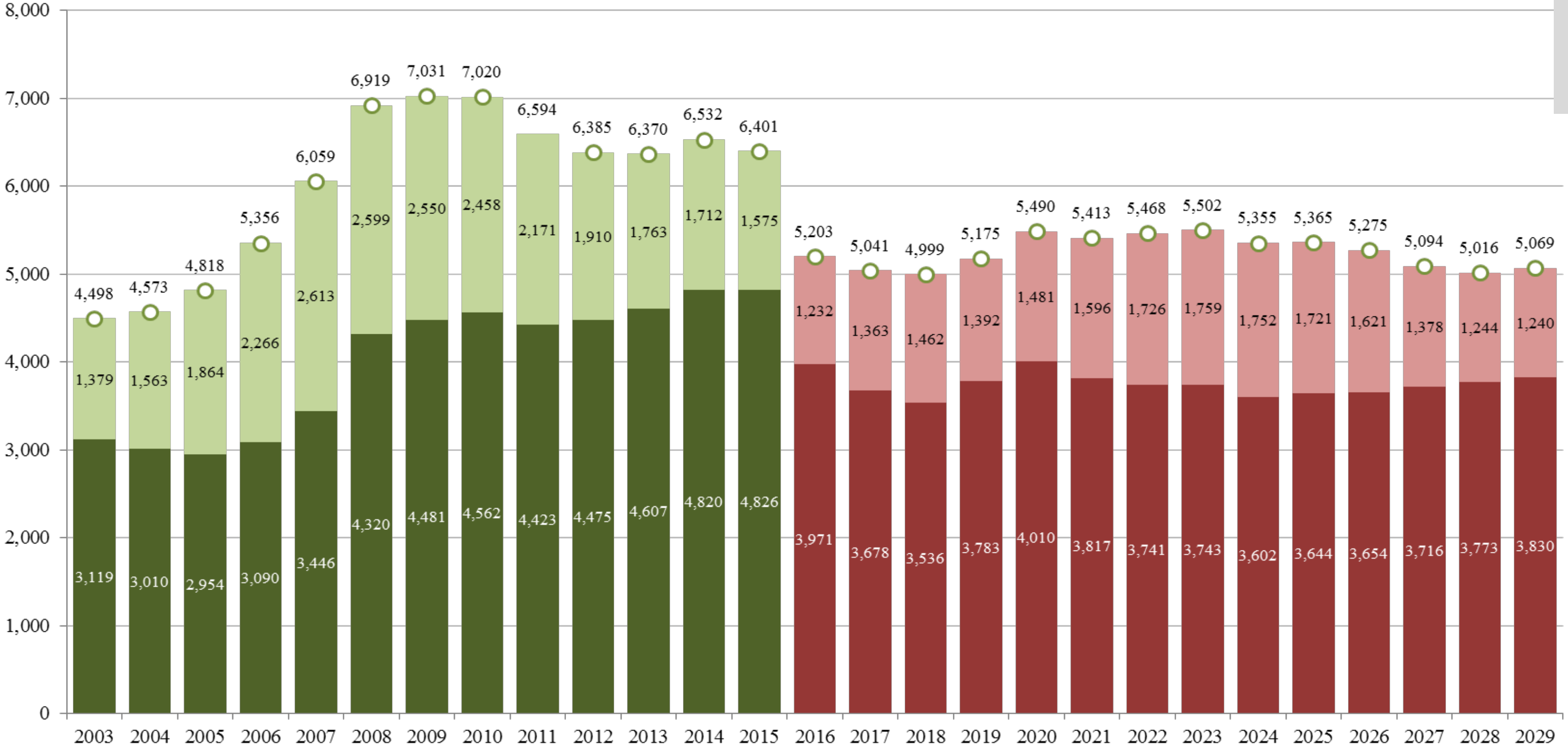
- Average natural gas production 3,690 MMcfd, which represents a 4% decrease in relation to the production registered in 2018. Associated hydrocarbon gas production represented 75% of total production, while non-associated gas corresponded to 25% .

Pemex Producción de gas natural y envío de gas a la atmósfera				
	Del 1 de enero al 31 de diciembre de			
	2018	2019	Variación	
Total (MMpcd)[1]	**3,841**	**3,690**	**-4.0%**	**(152)**
Asociado	2,828	2,754	-2.6%	(74)
No asociado	1,013	936	-7.7%	(78)
Envío de gas hidrocarburo a la atmósfera	**178**	**303**	**70.3%**	**125**
Envío de gas hidrocarburo / Total[2]	3.7%	6.2%	68.7%	0

[1] No Incluye nitrógeno ni producción de socios.
[2] A partir de 2016, el cálculo del índice de aprovechamiento de gas hidrocarburo, se basa en el manejo total de gas, incluyendo nitrógeno.
La suma de los parciales y los porcentajes de variación pudieran no coincidir debido al redondeo.

Natural Gas Production (mmcpd). SOURCE: SENER, 2016

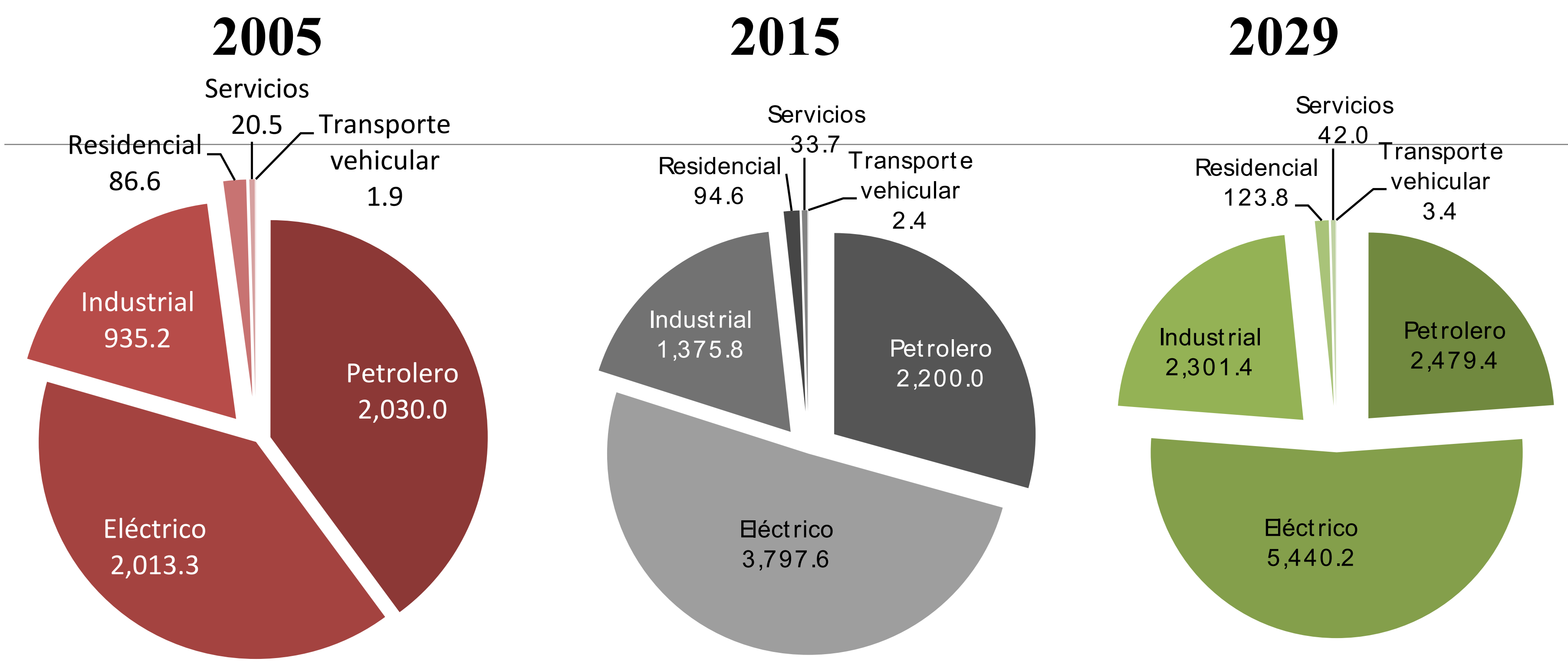
NATURAL GAS PRODUCTION HAS BEEN REDUCED IN THE RECENT YEARS DUE TO THE REDUCTION OF DRILLING ACTIVITIES AND WELL PREPARATION .
THERE ARE NO TENDER ACTIONS PROGRAMED FOR NATURAL GAS



GAS NO ASOCIADO

GAS ASOCIADO

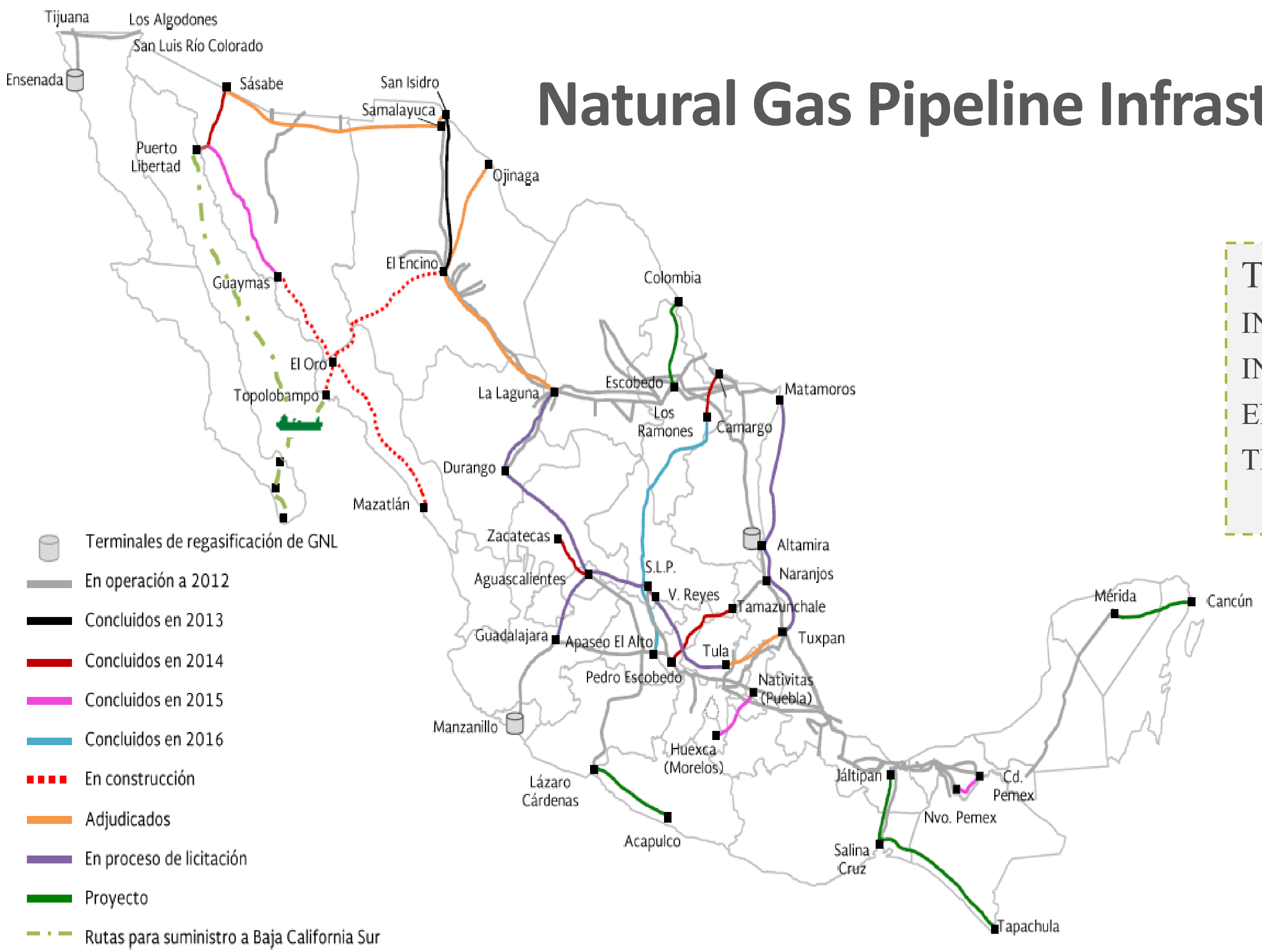
Natural Gas Demand (mmpcd), Source: SENER, 2016



5,087.5 MMPCD → 7,504.1 MMPCD → 10,390.2 MMPCD

OIL SECTOR IS EXPECTED TO GROW 13 % BY 2029

Natural Gas Pipeline Infrastructure. (Source: SENER, 2016)

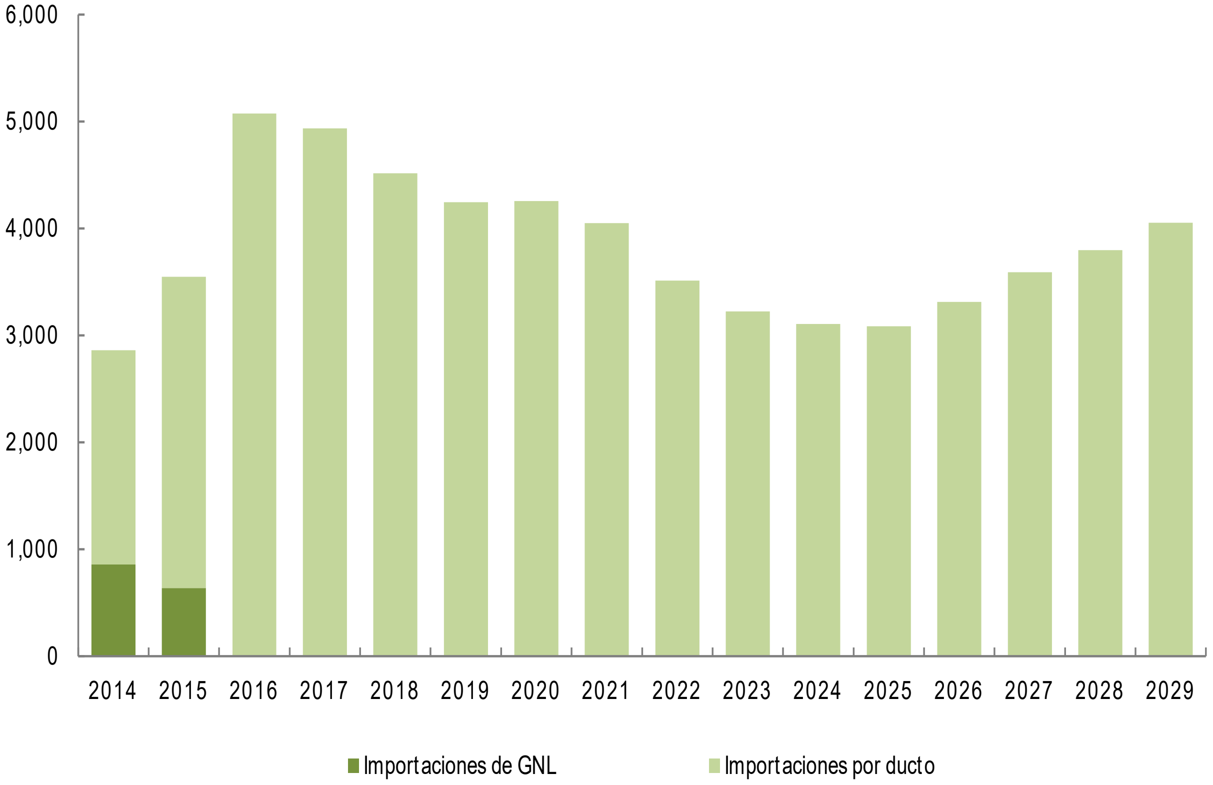


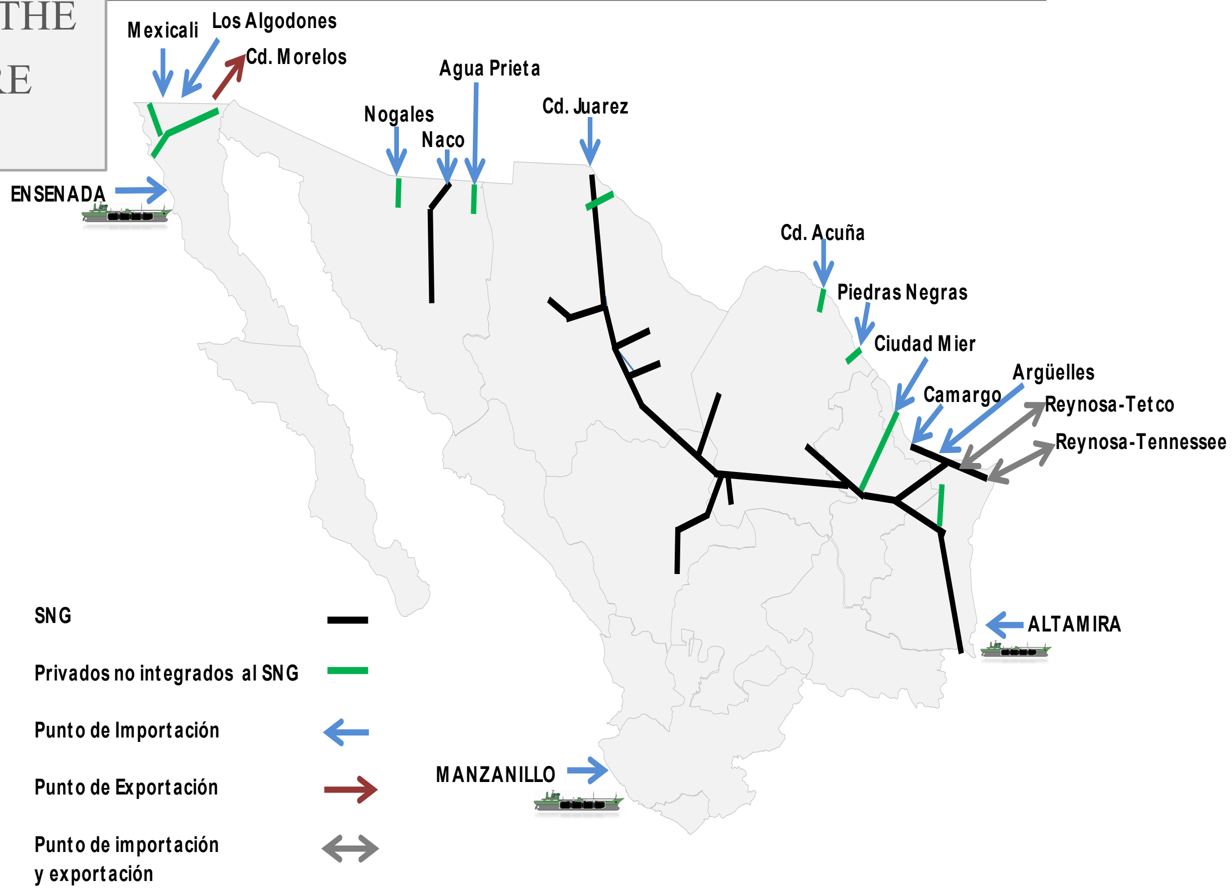
THE NATIONAL PLAN FOR INFRASTRUCTURE 2014-2018 INCLUDED SEVERAL PROJECTS TO ENHANCE NATURAL GAS TRANSPORTATION.

FUENTE: PROGRAMA DE DESARROLLO DEL SISTEMA ELÉCTRICO NACIONAL 2015-2029

Natural Gas Trade and Commerce, 2013-2028 (Source: SENER 2016)

IT IS EXPECTED THAT BY 2029 TOTAL IMPORTS OF NATURAL GAS INCREASE ITS VOLUME TO 4,052.2 MMPCD, AND PIPELINE IMPORTS INCREASE DUE TO THE DEVELOPMENT OF THE PIPELINE INFRASTRUCTURE





OUTLINE

1. CiiMAR´s brief introduction
2. Oil and Gas production in Mexican waters
3. National spill response capacity
4. Spillage, sources/volumes
5. Spillage effects on ecosystem and coastal communities.

✓ ***Protect the Marine Environment***

- Mexican Navy jurisdiction (Secretaría de Marina, SEMAR)

✓ **Federal Administration Law**

- Article 30

*“Intervene within its authority and jurisdiction to **protect and conserve the marine environment**”*

Source. Secretaria de Marina SEMAR

National Contingency Plan (PNC)

- ✓ Legal document
- ✓ Establishes the guidelines and procedures to act upon spills.
- ✓ Calls to the National organization for a quick response.

Source. Secretaria de Marina SEMAR

INSTITUTES & OCEANOGRAPHIC STATIONS OF THE NAVY

INSTITUTO OCEANOGRÁFICO
DEL GOLFO Y MAR CARIBE

ESTACIÓN OCEANOGRÁFICA
DE TOPOLOBAMPO

INSTITUTO OCEANOGRÁFICO
DEL PACÍFICO

ESTACIÓN OCEANOGRÁFICA
DE SALINA CRUZ

ESTACIÓN OCEANOGRÁFICA
DE CD. MADERO

ESTACIÓN OCEANOGRÁFICA
DE ENSENADA

ESTACIÓN OCEANOGRÁFICA
DE CIUDAD DEL CARMEN

ESTACIÓN OCEANOGRÁFICA
DE YUCALPETEN

Source. Secretaria de Marina SEMAR

PNC Objectives

Source. Secretaria de Marina SEMAR

- ✓ *Control and combat accidents.*
- ✓ *Coordinate and support contingency plan execution.*
- ✓ *Implement and timely respond with control and combat operations.*

PNC Members

✓ ***PNC Technical Council***

- President *(Mexican Navy)*
- Technical Secretary
- Federal Gov. Representatives

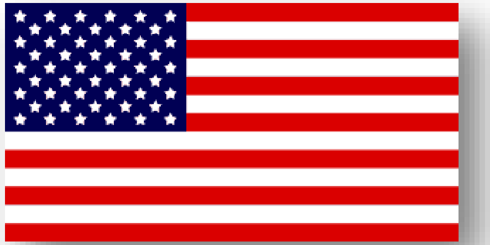
SEMAR Secretaría de Marina	SAGARPA Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación	SCT Secretaría de Comunicaciones y Transportes
SE Secretaría de Economía	SEDENA Secretaría de la Defensa Nacional	SEGOB Secretaría de Gobernación
SEMARNAT Secretaría de Medio Ambiente y Recursos Naturales	SENER Secretaría de Energía	SEP Secretaría de Educación Pública
SHCP Secretaría de Hacienda y Crédito Público	SALUD Secretaría de Salud	SRE Secretaría de Relaciones Exteriores
PEMEX	Cofepris	ASEA Agencia de Seguridad, Energía y Ambiente

Source. Secretaria de Marina SEMAR

Plan MEXUS

✓ ***A contingency plan between the United States of America and Mexico regarding pollution of the marine environment due to oil spills and other hazards substances and pollutants (Plan MEXUS).***

- Bilateral Plan
- SEMAR – US. Coast Guard.
- Created in 1980.
- Activates upon a Nations call



Source. Secretaria de Marina SEMAR

MEX-US OIL SPILL CONTINGENCY JOINT DRILLS

SOURCE: Dr. Sergio Jiménez, University of Tamaulipas

Figura A.1 – El MODU NOBLE DANNY ADKINS de la Compañía Shell

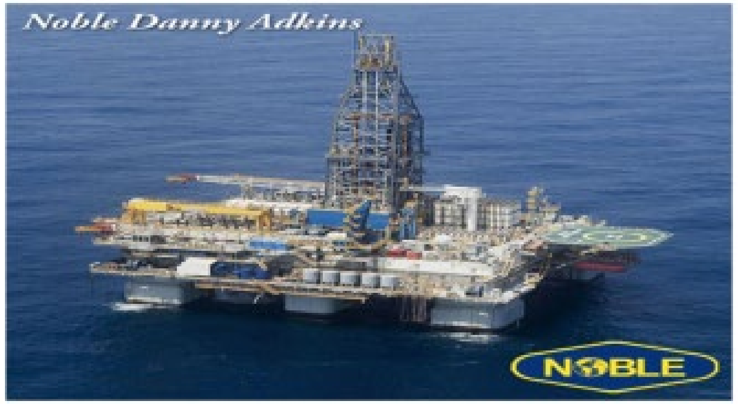


Figure A.2 – Ubicación del Incidente MODU NOBLE DANNY ADKINS

Figura A.5 - Zonas Ambientales Sensitivas en los EUA

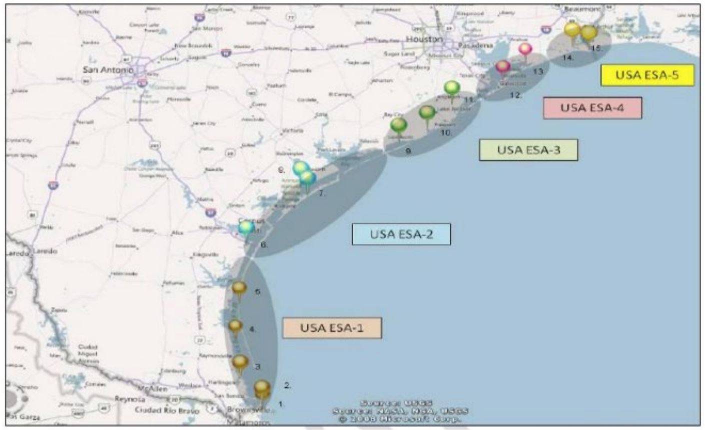


Figura A.4 – Zonas Ambientales Sensitivas en México

ARM RIO TECOLUTLA (BI-08)

ARM ONJUKU (BI-02)

ARM ANTARES (BI-04)

Source. Secretaria de Marina SEMAR

BUQUES OCEANOGRÁFICOS DE LA SECRETARÍA DE MARINA

ARM ALTAIR (BI-03)

ARM HONDO (BI-06)

ARM HUMBOLDT (BI-01)

OUTLINE

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2. Oil and Gas production in Mexican waters
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Quantification of oil spills

- In 2019, 1092 events related to leaks and spills were registered, an increase of 16% compared to the 2018 period. The increases in the 2018 and 2019 periods compared to previous years are greater because all the events were considered.

	2014	2015	2016	2017	2018*	2019*
Number of events	159	209	192	223	912	1092
Volume released (b)	5110	1164	8120	506	1374	1717
Volume released (MMpc)	83	24	18	5	41	32.1

*Se incluyen los eventos reportados con fuga y derrame, no incluye eventos por tomas clandestinas

- Events corresponding to the period 2019

Source. PEMEX 2019

EPS	Eventos	%
Pemex Exploración y Producción	851	77.9
Pemex Logística	199	18.2
Pemex Transformación Industrial	41	3.8
P.M.I. Pemex Comercio Internacional, S.A. de C.V.	1	0.1
Totales	**1,092**	**100%**

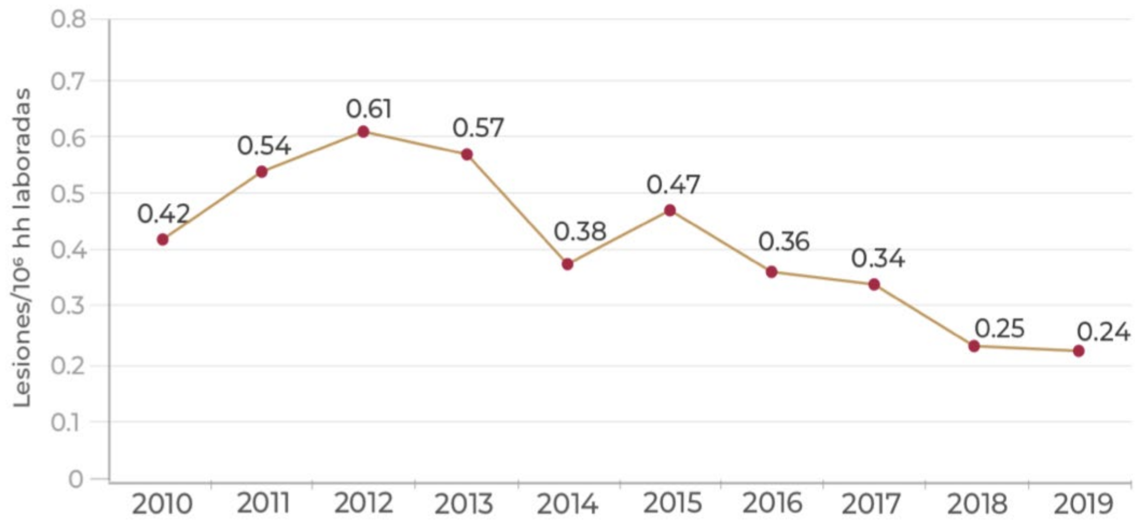
Accidents follow up and reports

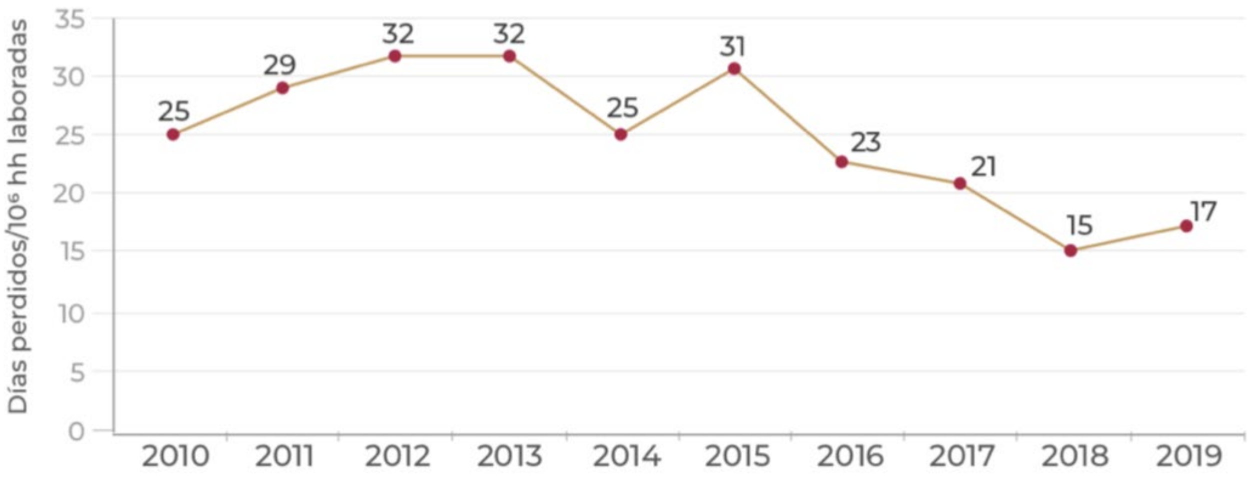
Facility/infrastructure	Reports and root cause analysis	Follow up reports and recommendations
Plataforma Arenque B	1	
Pozo Ayocote 7	1	
Oleoducto Marsopa-Punta de Piedra	1	
Pozo Furbero 1190	1	
UP Comalcalco	1	
Refinería Minatitlán	1	
TAD Mazatlán	1	
Plataforma Abkatún A-Permanente		4
TAD Salamanca		3
Taller de Combustión Poza Rica		2
Plataforma Abkatún-A-Compresión		1
Plataforma Arenque C		1
Estación Compresión Tamaulipas 3		1
Macropera Nejo 2D		1
TAD Saltillo		1
Barco Grúa Fénix	1	1
Plataforma Chac-A	1	1
Plataforma Ixachi 2	1	1
Plataforma Nohoch-A	1	1
Refinería Salina Cruz	1	1
Refinería Tula	1	1

Source. PEMEX 2019

ACCIDENTS, FREQUENCY INDEX.

ACCIDENTS, SEVERITY INDEX





Source. PEMEX 2019

Events with 100% recommended actions finished in 2019

Eventos cuyas recomendaciones se cerraron al 100% durante 2019		
Centro de Trabajo / Instalación	**Fecha de ocurrencia del evento**	**Fecha de atención de las recomendaciones**
Plataforma Abkatún-A-Permanente	1 de abril de 2015	Diciembre de 2019
Plataforma Abkatún-A-Compresión	7 de febrero de 2016	Enero de 2019
Refinería Salina Cruz	14 de junio de 2017	Julio de 2019
Estación de Compresión Tamaulipas 3	27 de diciembre de 2017	Noviembre de 2019
Taller de combustión Poza Rica	6 de junio de 2018	Abril de 2019
Macropera Nejo 2D	5 de marzo de 2018	Marzo de 2019
Plataforma Arenque C	26 de junio de 2018	Octubre de 2019
TAD Saltillo	5 de julio de 2018	Marzo de 2019
Plataforma Habitacional Nohoch-A	6 de noviembre de 2018	Julio de 2019
Barco Grúa Fénix	24 de mayo de 2019	Diciembre de 2019
Plataforma Chac-A	15 de agosto de 2019	Diciembre de 2019

Source. PEMEX 2019

Approach and application of level 4 proactive indicators

- Pemex has proactive indicator metrics, using indicator dashboards it monitors each one of them in a preventive manner.

Indicador	% de cumplimiento
Contratistas	99.5
POPS: Calidad	98.5
Respuesta a Emergencias	98.1
Administración de Cambios de Personal	96.7
POPS: Disponibilidad	94.5
Entrenamiento y Desempeño	93.9
Tecnología del Proceso	93.2
Administración de Cambios	92.9
Investigación y Análisis de Accidentes	89.4
POPS: Cumplimiento	89.0
Cumplimiento de recomendaciones de ASP	87.0
POPS: Comunicación	85.1
Integridad Mecánica	84.6
Análisis de Riesgos	82.8
Auditorías	72.7

Source. PEMEX 2019

Accidents frequency index in the sector

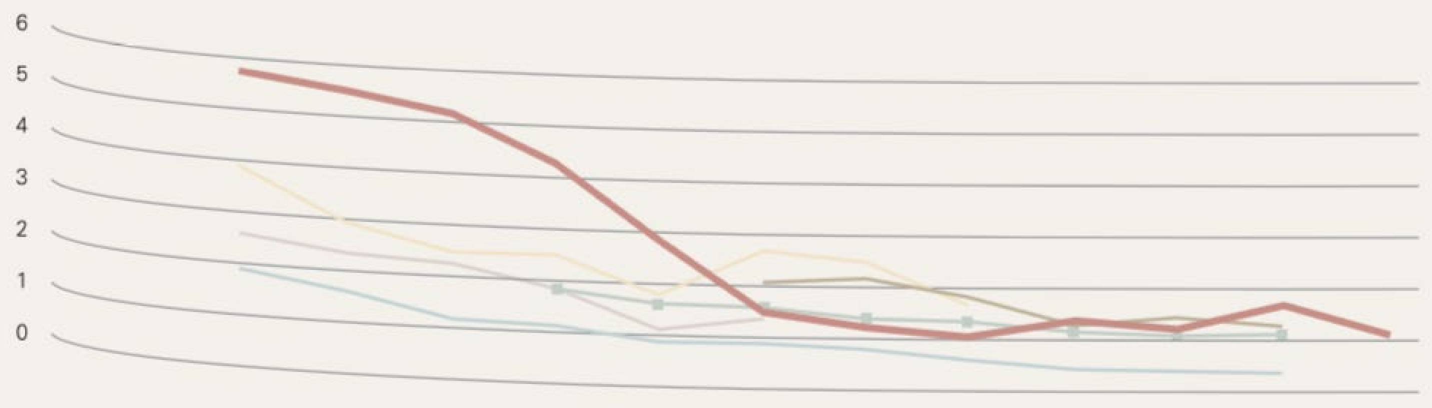
Pemex frequency index VS other oil companies

Source. PEMEX 2019

ÍNDICES DE FRECUENCIA EN EL SECTOR[2]

ÍNDICE DE FRECUENCIA DE PEMEX VS. OTRAS EMPRESAS PETROLERAS

frecuencia



	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005
PEMEX	5.80	5.30	4.90	4.00	2.68	1.39	1.19	1.00	1.17	1.09	1.50	1.06
BP & AMOCO	2.2	1.8	1.3	1.2	0.9	0.9	0.8	0.6	0.4	0.4	0.4	
A.P.I. PROM.	4.0	3.0	2.5	2.4	1.7	2.5	2.3	1.5				
TEXACO	2.8	2.5	2.3	1.6	1.2	1.3						
SHELL incluye contratistas				1.6	1.6	1.4	1.3	1.2	1.1	1.0	1.0	
CHEVRON TEXACO						1.9	2.0	1.7	1.3	1.3	1.1	

Spill and Leak Log 2005

REGISTRO DE DERRAMES Y FUGAS 2005

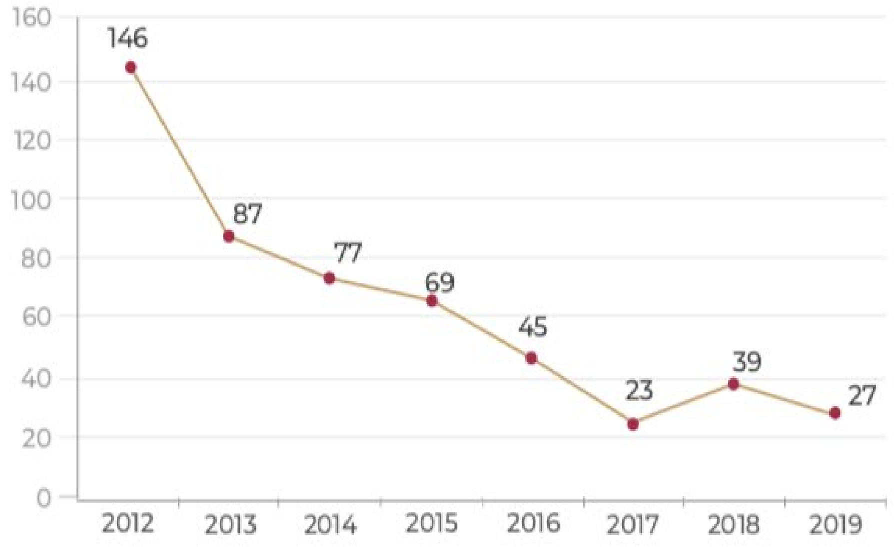
	SPILLS (LIQUIDS)			LEAKS (GAS)		TOTALS LEAKS + SPILLS	
ORGANISMO	Número registrado	Volumen estimado (bls)	Cantidad estimada (ton)	Número registrado	Cantidad estimada (ton)	Número registrado	Cantidad estimada (ton)
PEMEX- Exploración y Producción [1)]	226	1,502.00	211.00	102	19.00	**328**	**230.00**
PEMEX-Gas y Petroquímica Básica	1	481.00	68.00	7	248.00	**8**	**316.00**
PEMEX-Refinación	55	20,613.00	2,901.00	6	1.00	**61**	**2,902.00**
PEMEX-Petroquímica	1	0.06	0.01	1	80.00	**2**	**80.01**
Total PEMEX	**283**	**22,596.06**	**3,180.01**	**116**	**348.00**	**399**	**3,528.01**

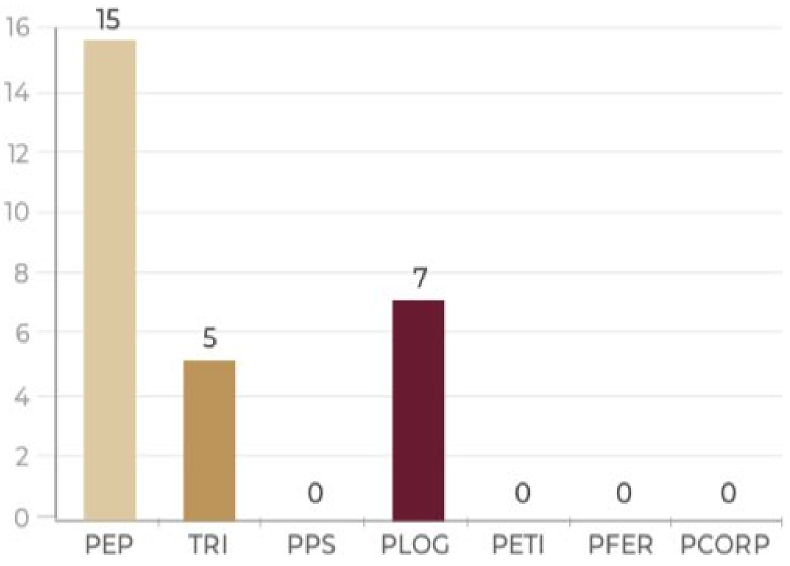
[1)] Incluye únicamente los derrames y fugas de los sistemas de transporte de hidrocarburos por ductos.

Processes safety

Process safety events classified as level 1

- During 2019, 27 safety events were registered.
- The largest number of events occurred at Pemex *"Exploración y producción"*





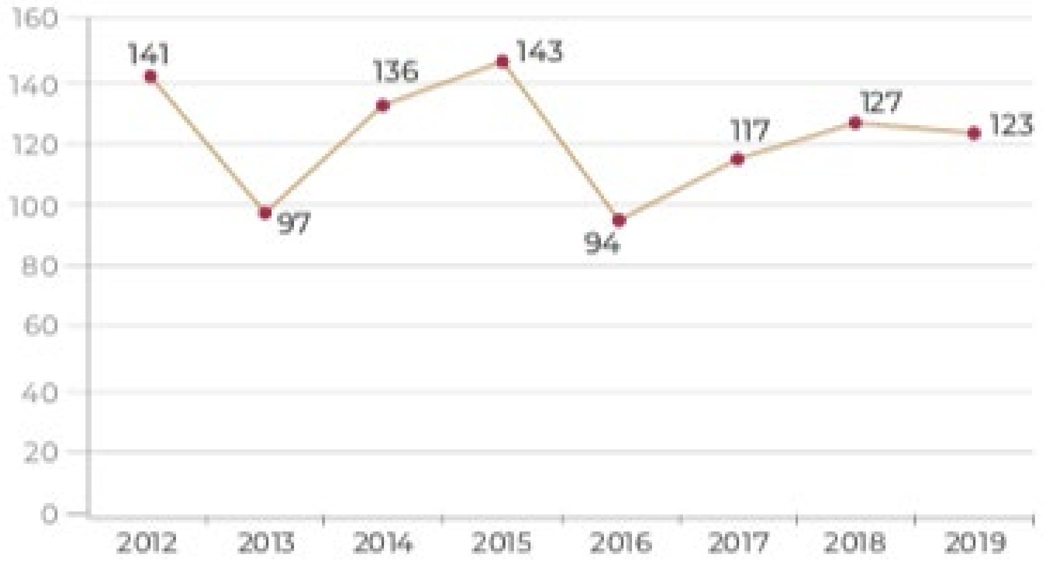
Level 1 events (2012-2019)

Level 1 events (2019)

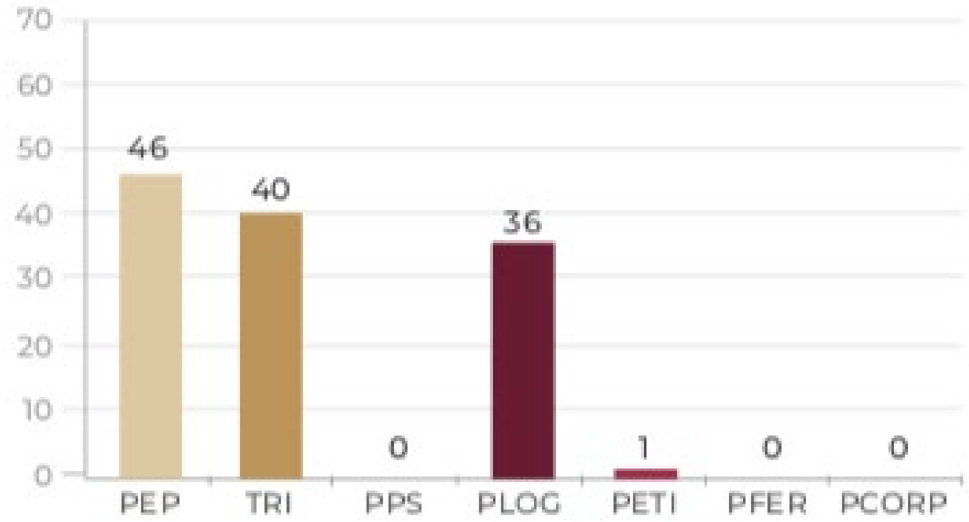
Source. PEMEX 2019

Process safety events classified as level 2

- During 2019, 123 safety events were registered.
- The largest number of events occurred at Pemex *"Exploración y producción"*



Level 2 events (2012-2019)

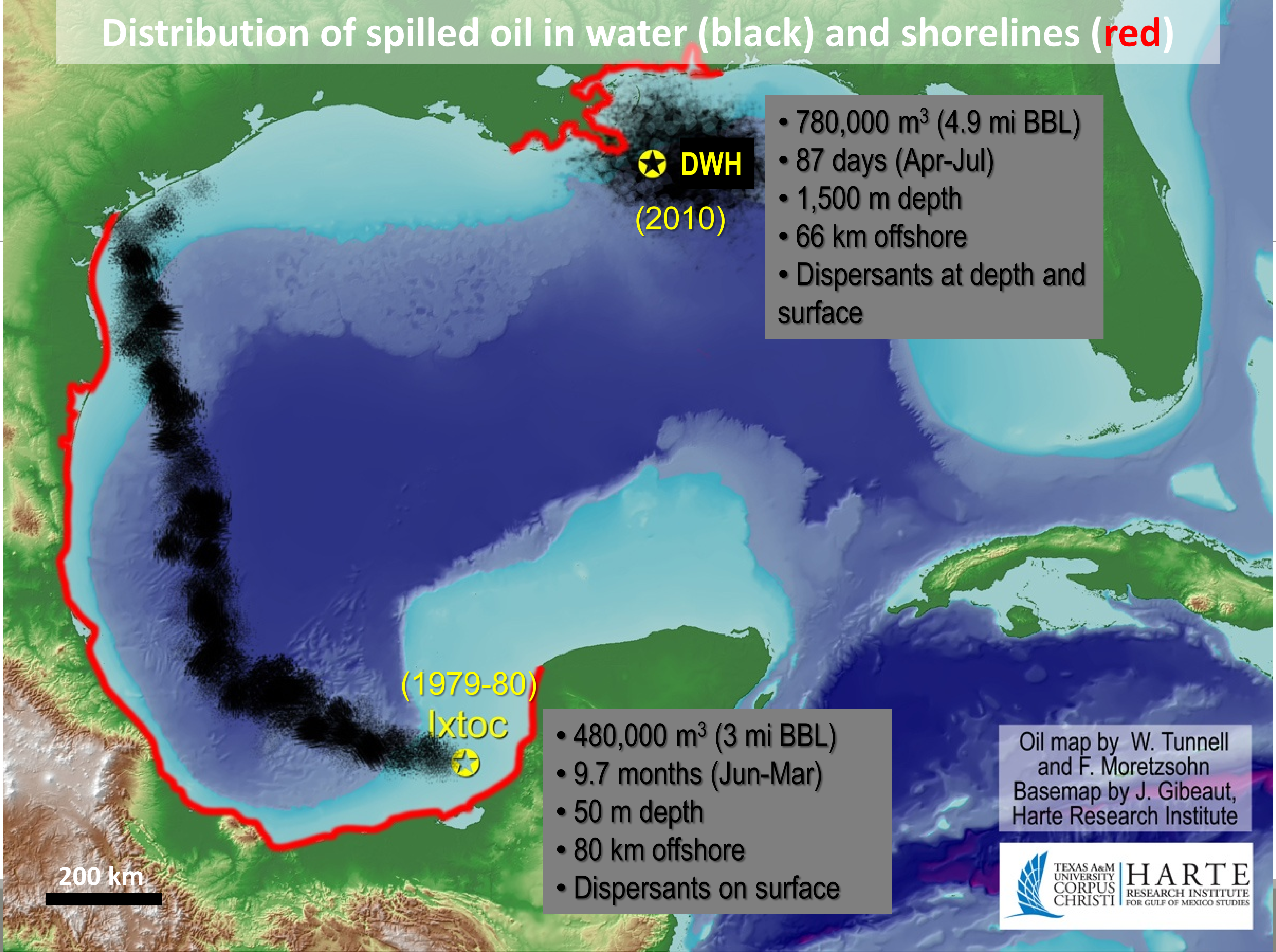


Level 2 events (2019)

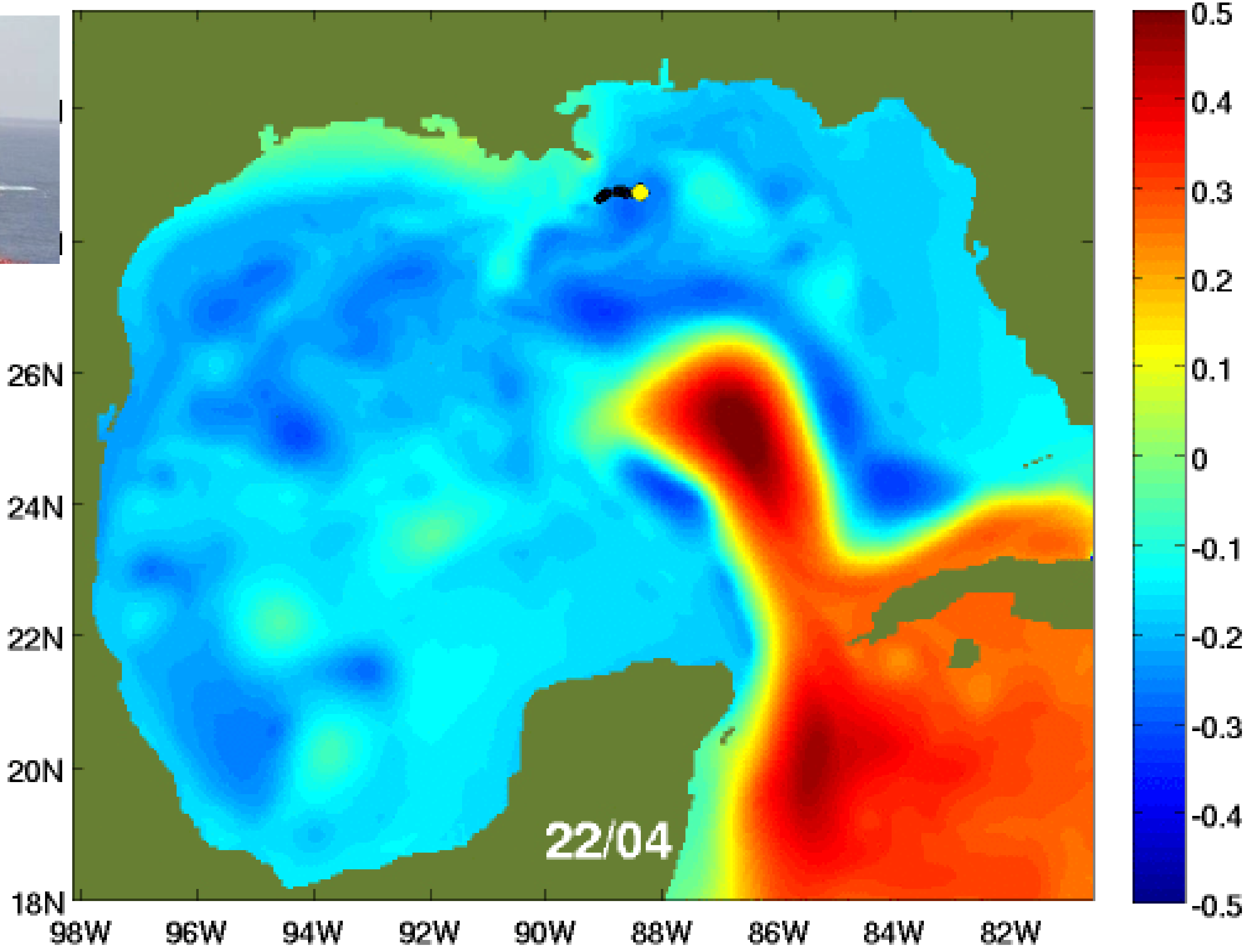
Source. PEMEX 2019

OUTLINE

1. CiiMAR´s brief introduction
2. Oil and Gas production in Mexican waters
3. National spill response capacity
4. Spillage, sources/volumes
5. Spillage effects on ecosystem and coastal communities.

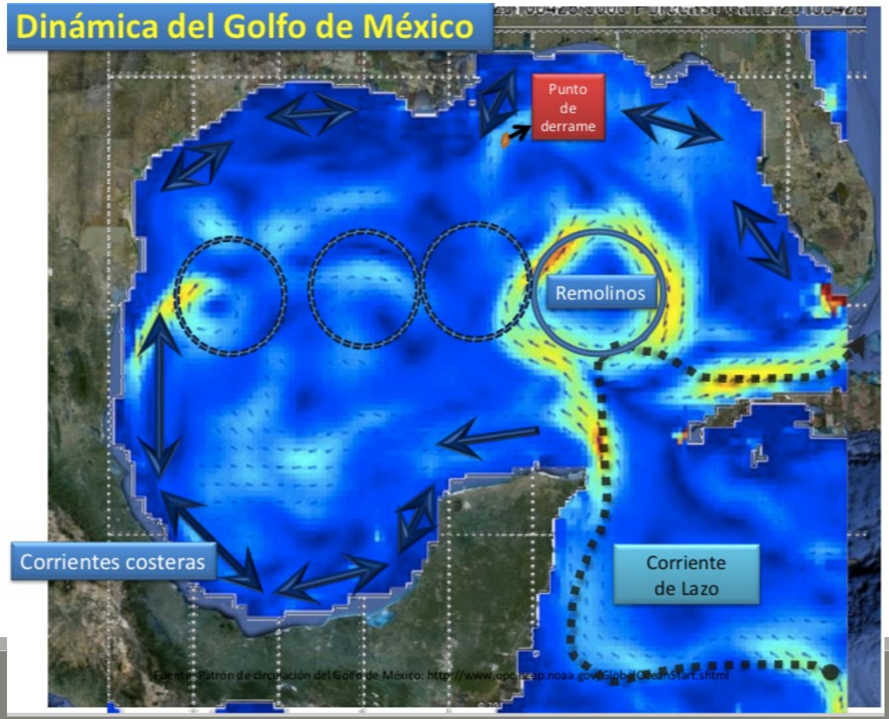

Distribution of spilled oil in water (black) and shorelines (red)
DWH
(2010)
• 780,000 m³ (4.9 mi BBL)
• 87 days (Apr-Jul)
• 1,500 m depth
• 66 km offshore
• Dispersants at depth and surface
(1979-80)
Ixtoc
• 480,000 m³ (3 mi BBL)
• 9.7 months (Jun-Mar)
• 50 m depth
• 80 km offshore
• Dispersants on surface
Oil map by W. Tunnell and F. Moretzsohn
Basemap by J. Gibeaut, Harte Research Institute
TEXAS A&M UNIVERSITY CORPUS CHRISTI
HARTE RESEARCH INSTITUTE FOR GULF OF MEXICO STUDIES
200 km

Oil Spill, BP managed Deepwater Horizon,

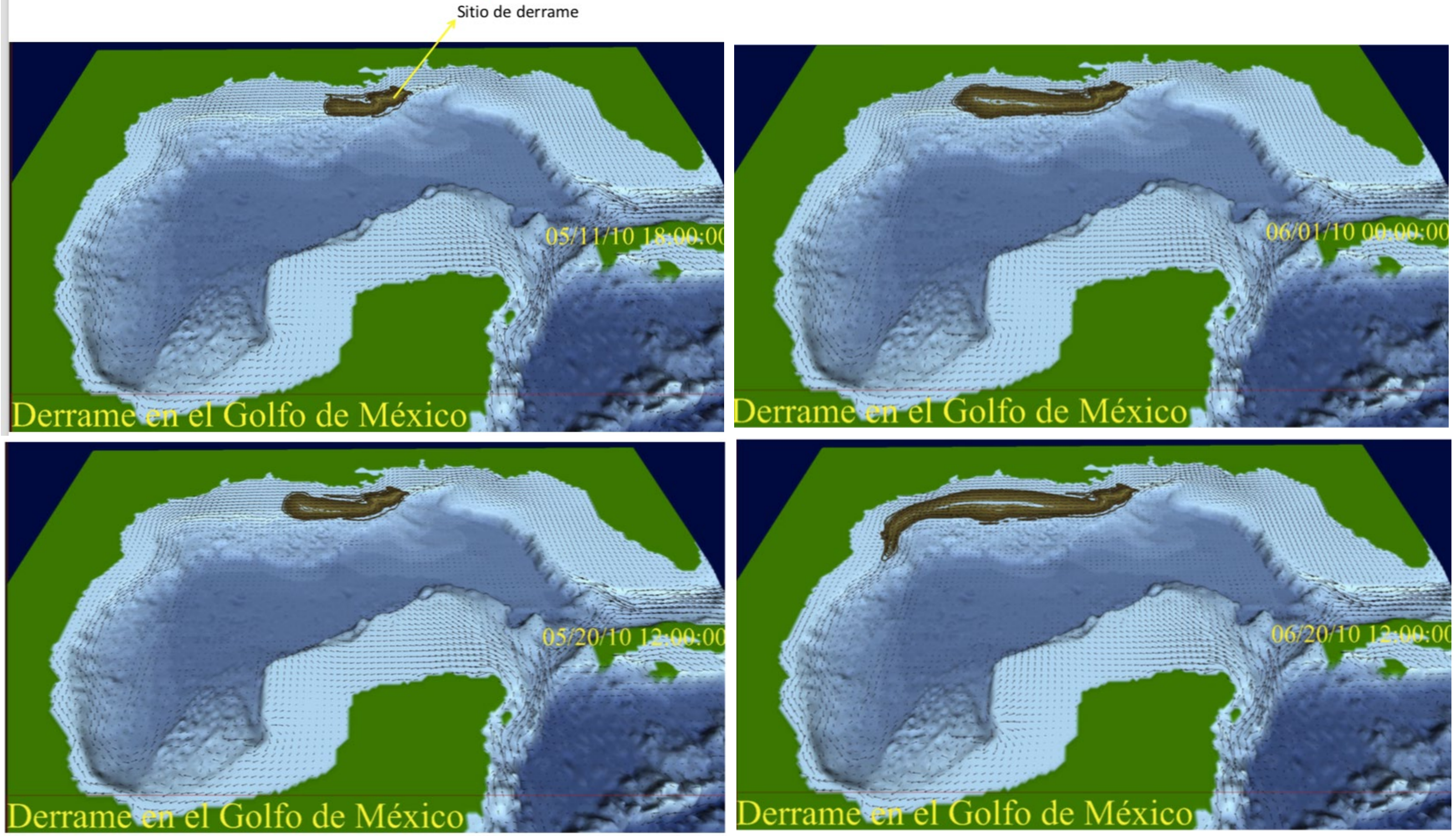


Derrame de petróleo en el Golfo de México: Plataforma Marina Deepwater Horizon

Escenarios posibles de dispersión
Por: Dr. Sergio Jiménez Hernández
Universidad Autónoma de Tamaulipas



Simulación del derrame del dispersante



Source. Universidad Autónoma de Tamaulipas
Dr Sergio Jiménez Hernández

Oil Spills in coastal areas
2000-2014 (CNH)

Estado	Litros
Tabasco	**5´964,082**
Veracruz	4´762,364
Chiapas	2´714,992
Puebla	1´097,865
Campeche	192,868
Tamaulipas	89,016
Nuevo León	14,836
Total	**14´836,025**

Total volume spill in **442 events** in Tabasco State, represents **40 %** of the total national.

Source: Comisión Nacional de Hidrocarburos.

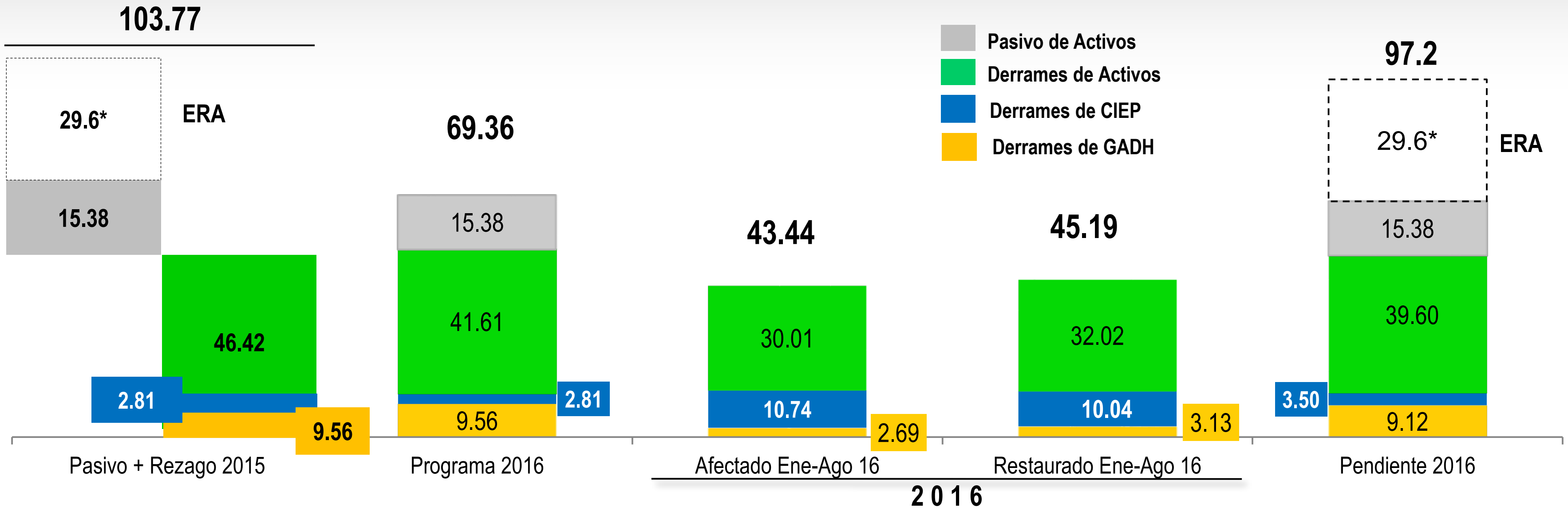
Source. SERNAPAM TABASCO

Impacts by type

- Agriculture production.
- Soil, water and air pollution.
- Dead animals.
- Water retention, flooding.
- Damage to fisheries resources, agriculture and livestock
- Damage to public infrastructre and local people households.

Source. SERNAPAM TABASCO

RESTORATION PROCESS
Terrestrial areas



Dependencia	Rezago		Programa de atención 2016		Afectado Ene-Ago 2016	Restaurado Ene-Ago 2016			Pendiente Total		
	Pasivo	Emergencias	Pasivo	Emergencias		Pasivo	Emergencias (Rezago)	Emergencias 2016	Pasivo	Emergencias (Rezago)	Emergencias 2016
Activos de Producción	44.98	46.42	15.38	41.61	30.01	0.00	8.41	23.61	44.98	33.20	6.4
Áreas Contractuales (CIEP)	0.00	2.81	0.00	2.81	10.74	0.00	1.26	8.78	0.00	1.54	1.96
GADH	0.00	9.56	0.00	9.56	2.69	0.00	1.85	1.28	0.00	7.71	1.41
Total	44.98	58.79	15.38	53.98	43.44	0.00	11.52	33.67	44.98	42.45	9.77
	103.77		69.36			45.19			97.2		

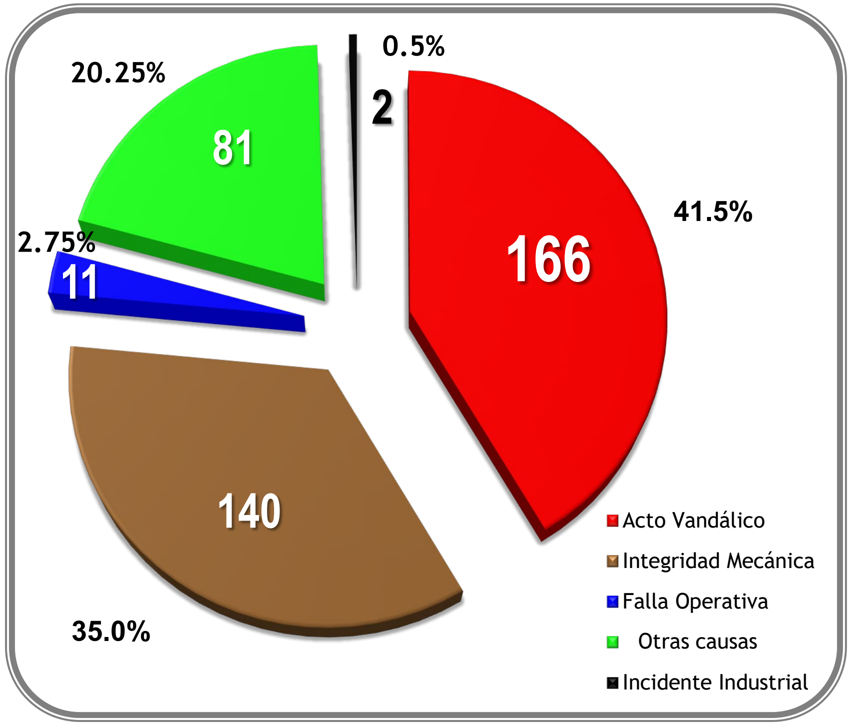
** SE REALIZARÁN ESTUDIOS DE EVALUACIÓN DE RIESGO AL AMBIENTE Y A LA SALUD EN 29.60 HAS (23.84 DE ÁREAS ALEDAÑAS AL CPGLV Y 5.76 DE LA LAGUNA EL LIMÓN).*

PEMEX EXPLORACION Y PRODUCCION ®

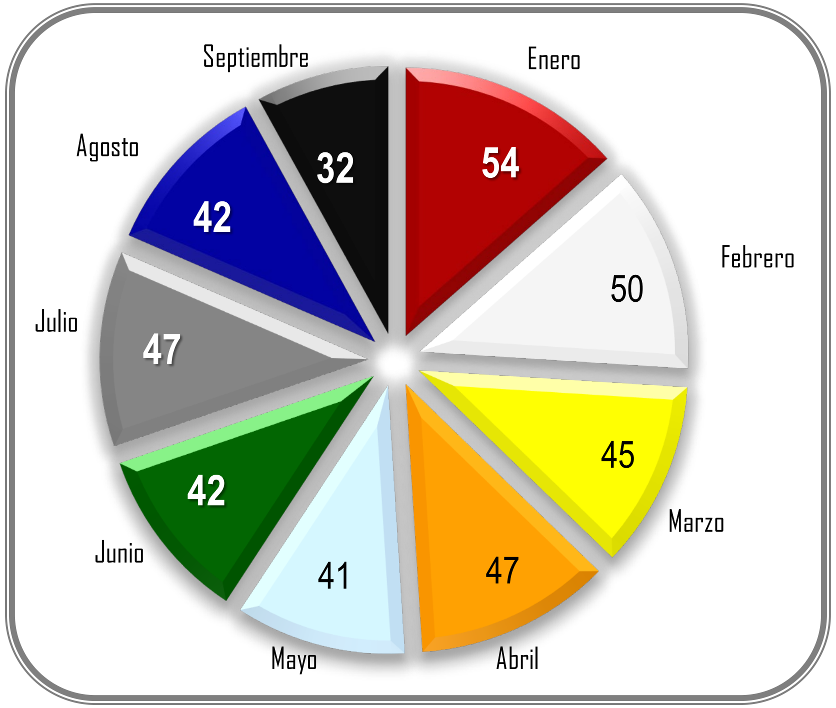
Environmental Emergencies 2016

SPILLS AND LEAKS

ACCIDENT CAUSE

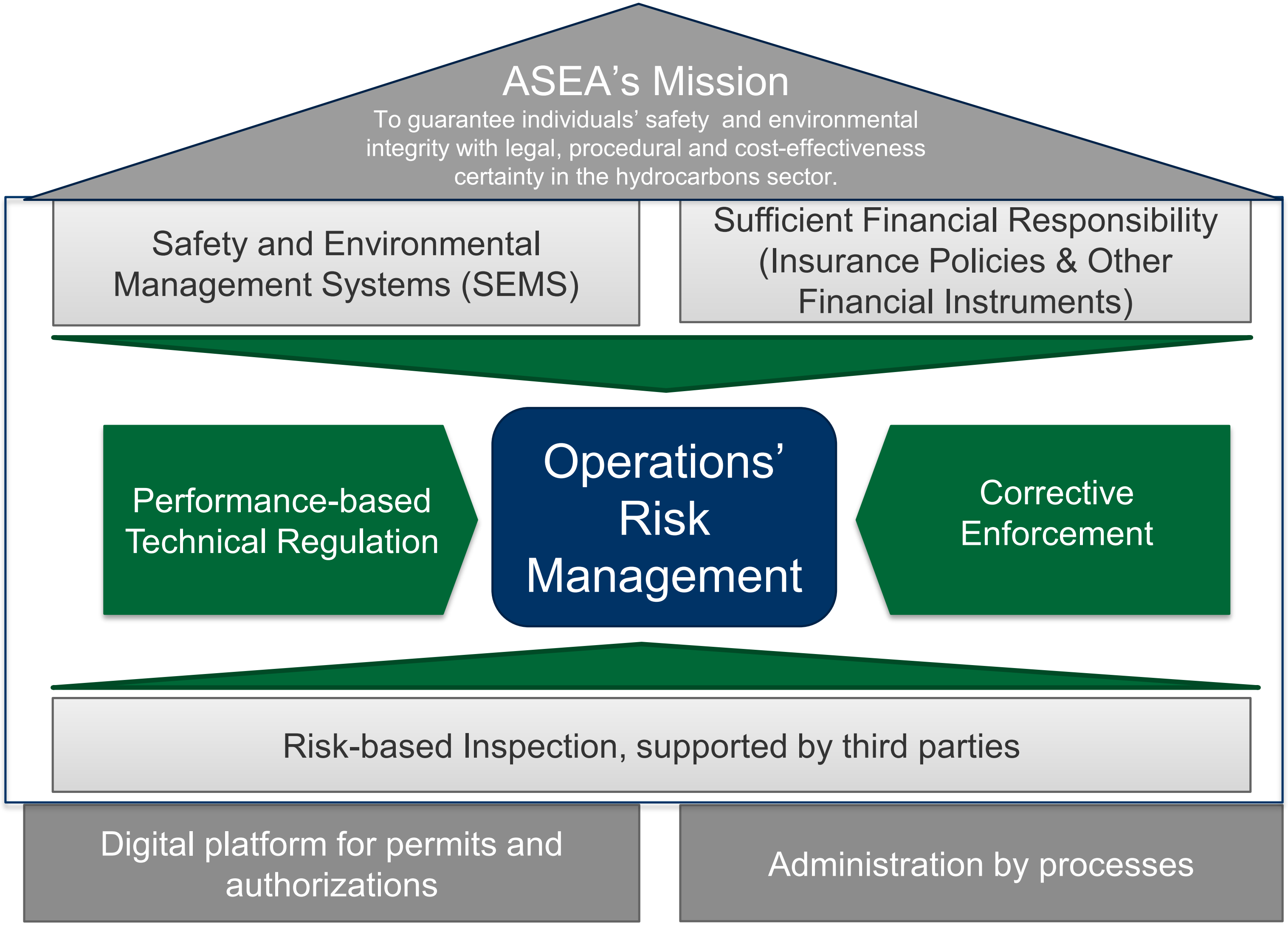


MONTHLY STATS



Total 400 events

ASEA'S INSTITUTIONAL DESIGN



ASEA's regulatory framework for offshore operations

GENERAL PROVISIONS FOR HYDROCARBONS EXPLORATION & PRODUCTION

- Published on December, 9th, 2016 in the Official Gazette
- Regulates **Offshore** activities (shallow and deep waters) for hydrocarbons exploration and production
- Based on **international best practices** (USA, Canada,, Norway, United Kingdom and Brazil, among others).
- **Harmonized with US GoM regulation**
- Based on **industry standards** (API, ISO, NORSOK, IEC)
- **Opinions** from national and international energy sector entities, the academic sector, private sector organizations and a wide public consultation have been considered.

SEMARNAT
SECRETARÍA DE MEDIO AMBIENTE Y RECURSOS NATURALES

ASEA
AGENCIA DE SEGURIDAD, ENERGÍA Y AMBIENTE

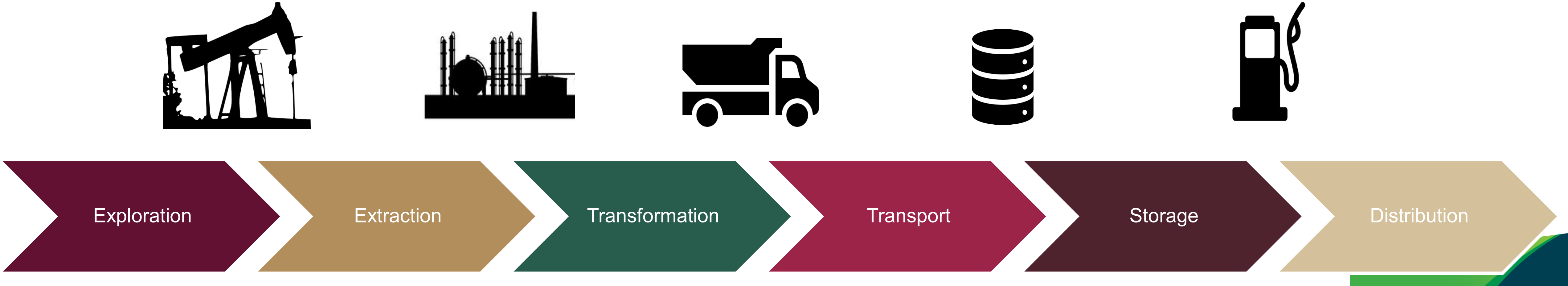
ENVIRONMENTAL IMPACT ASSESSMENT AND BASE LINE

- Hydrocarbons operators must present to ASEA an **Environmental Impact Assessment Study** and an **Environmental Base line.**
- ASEA assesses and emits resolution on EIA (Rules of the General Law for ecological balance and environmental protection)
- ASEA assesses and emits opinion on the Environmental Base line (contract)

Base line Guideline for Offshore activities:

http://www.gob.mx/cms/uploads/attachment/file/173934/GUIA_LBA_MARINA-FINAL_131216.pdf

→ implies relying on the environmental information presented by Hydrocarbons Operators



Scope

EXPLORATION

- 368,284 km sísmica 2D
- 413,376 km² sísmica 3D

EXTRACTION

- +30,000 pozos terrestres
- 350 plataforma marinas

INDUSTRIALIZATION

- 7 Refinerías
- 9 Procesadoras de gas

TRANSPORT

- +60,000 km. de ductos
- 2,600 semirremolques
- 33 buque-tanques
- 6 empresas con permiso de carro-tanques

ASEA
AGENCIA DE SEGURIDAD, ENERGÍA Y AMBIENTE

STORAGE

- 111 Terminales de almacenamiento de líquidos
- 30 Permisos de almacenamiento de Gas L.P.
- 4 Permisos de almacenamiento de Gas Natural

DISTRIBUTION AND PUBLIC SELL

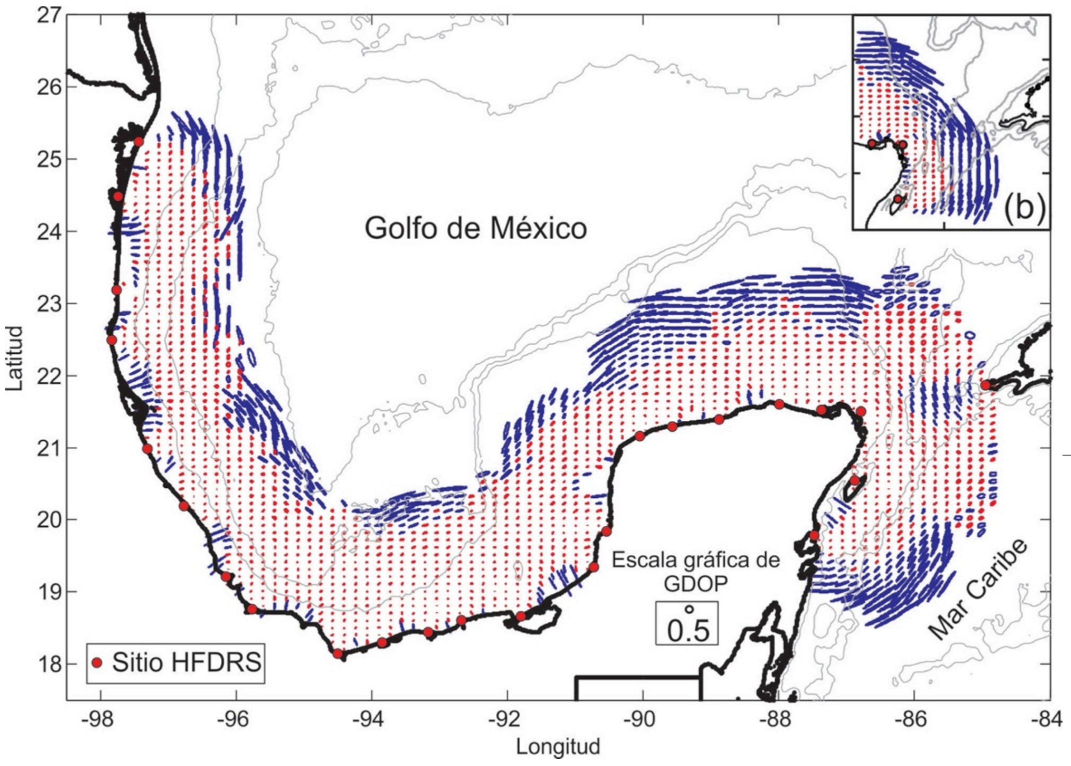
- +12,000 Estaciones de servicio de diésel y gasolina
- +20,000 Vehículos para la distribución de Gas L.P.
- 1,097 Plantas de distribución de Gas L.P.
- +50,000 km. de Gas Natural por medio de ductos
- 2,274 Estaciones de servicio con fin específico de expendio de Gas L.P.
- 55 Estaciones de suministro de vehículos automotores GNC

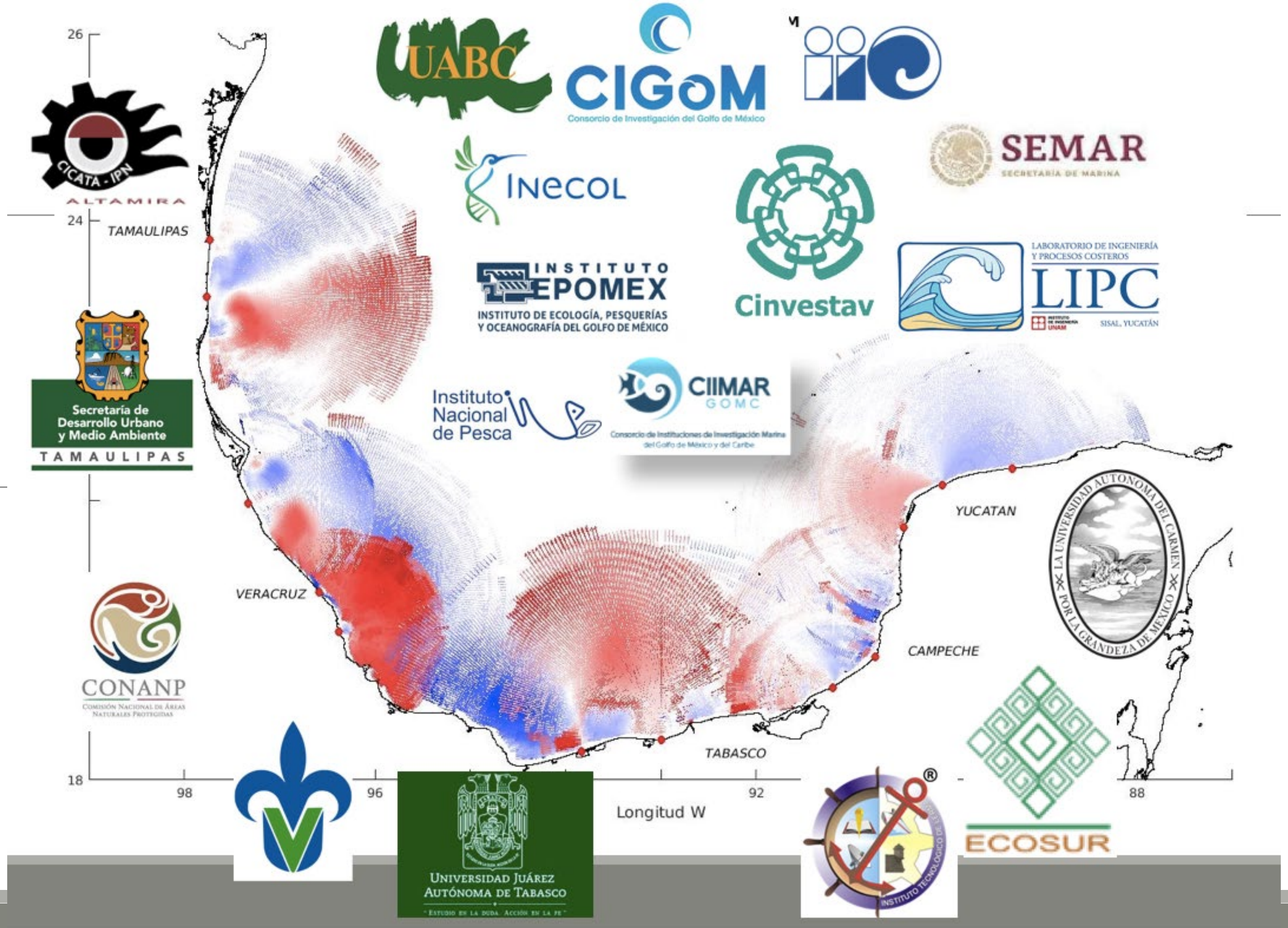
CIIMAR GOMC
Consorcio de Instituciones de Investigación Marina del Golfo de México y del Caribe

Universidad Juárez Autónoma de Tabasco
" Estudio en la duda. Acción en la fe "

Monitoring the Gulf of Mexico and Caribbean Sea with High Frequency Radars Project started in 2015

Source. Uniersidad Autónoma de Baja California

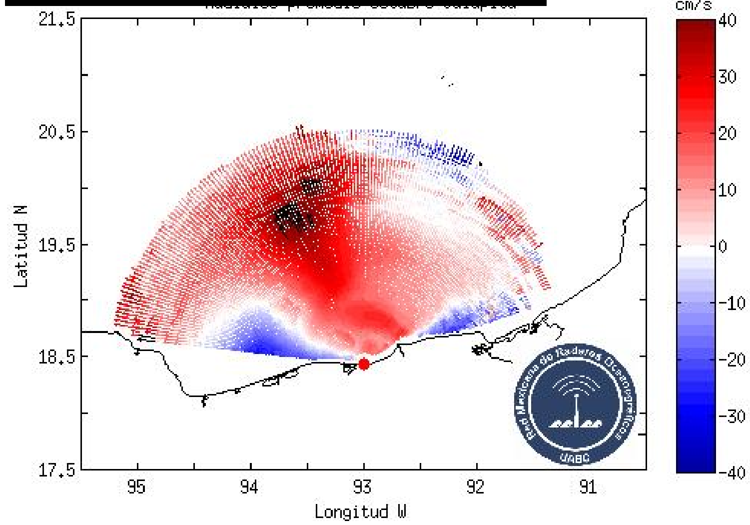




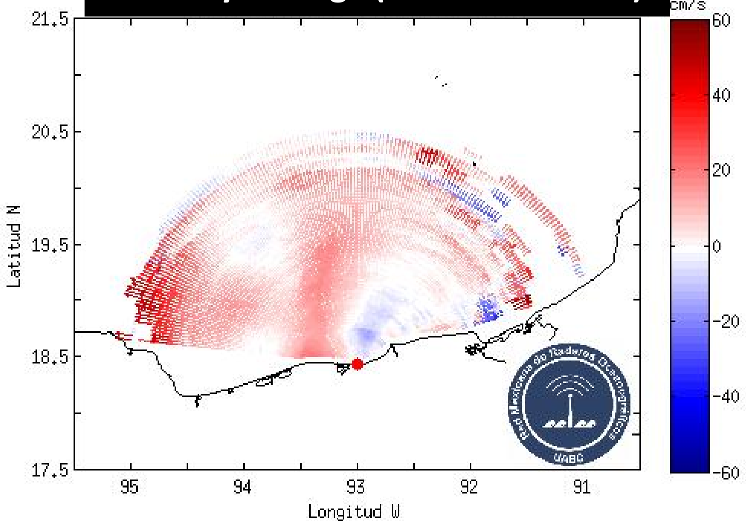
Source. Uniersidad Autónoma de Baja California

HFR IN THE CAMPECHE SOUND

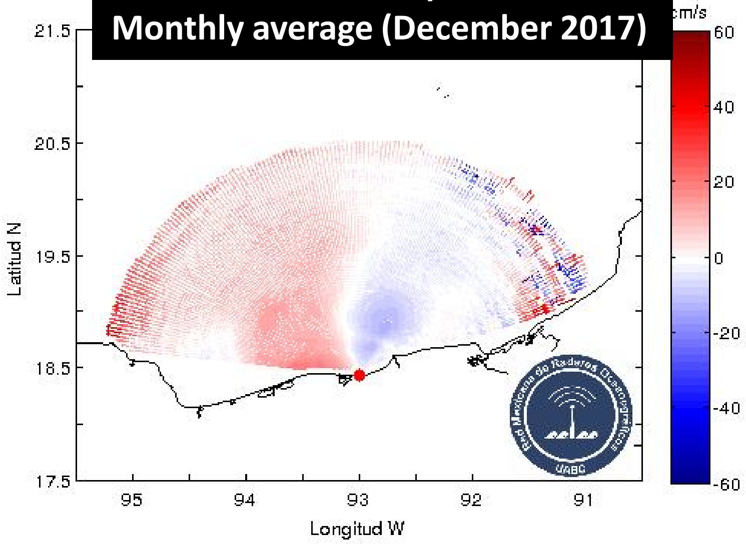
Radial Currents, Jalapita Site
Monthly average (October 2017)



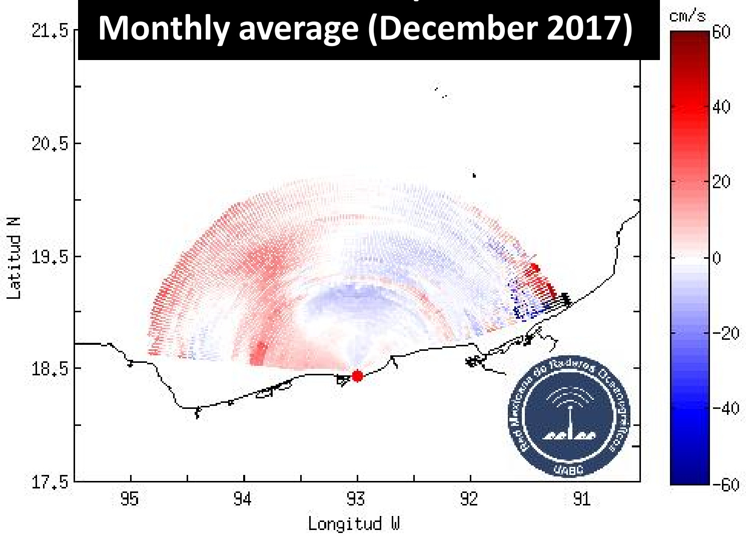
Radial Currents, Jalapita Site
Monthly average (November 2017)



Radial Currents, Jalapita Site
Monthly average (December 2017)



Radial Currents, Jalapita Site
Monthly average (December 2017)



Technical Training

Capacity building

The IMP has the technological competences to participate in the development of shallow and deep water oil fields, the CTAP will allow to improve these capacities

Shallow waters

Intermediate waters

Deep waters

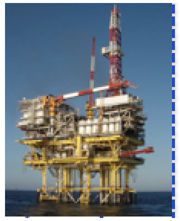
1976 | 1978 | 1980 | 1982 | 1984 | 1986 | 1988 | 1990 | 1992 | 1994 | 1996 | 1998 | 2000 | 2002 | 2004 | 2006 | 2008 | 2010 | 2012 | 2014 | 2016 | 2018

First fixed platforms designed by the IMP in 1978 for Pemex oil fields in shallow waters (<100 m)

KEY ISSUES FOR TECHNOLOY IMPROVEMENT:

- Training of human resources
- Development of tools or devices for operation and optimization
- Research and implementation of technologies in facilities

Establishment of Mexican rules to the design, inspection and maintenance of fixed platforms and pipelines (1996 to date)



In 2005, development of skills to design fixed platforms for 350 m of water depth.

Since 2006, assimilation program to acquire capabilities to design floating production systems, subsea equipment, foundations, risers and pipelines

The CTAP will start operations in 2017

The CTAP will include six laboratories during its first phase

CTAP STRUCTURE

Drilling
- Drilling fluids and well completion and cementation
- Mechanics of well drilling and completion

Risks
- Flow assurance
- Geotechnics and ground-structure interaction
- Numerical simulation of metaoceanic and hydrodynamic phenomena

Equipment and systems
- Technology qualification
- Components of submarine equipment
- Control systems
- Process equipment
- Marine structures
- Tests of systems integration
- Hydrodynamics: oceanic tank

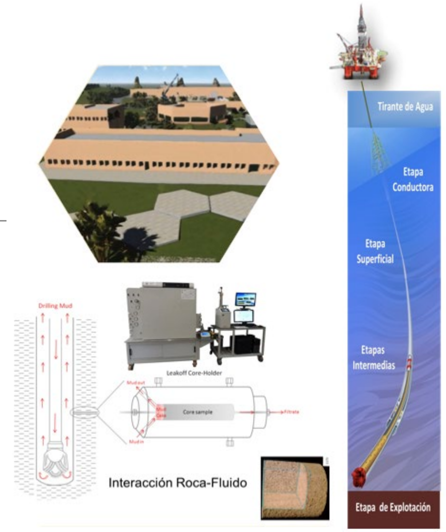
First phase

Second phase

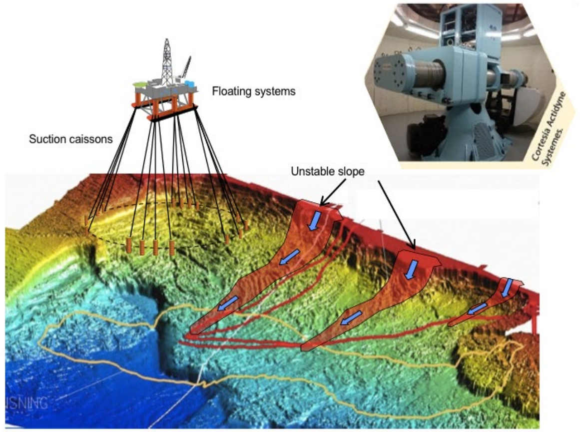
Third phase

FUNDING:
- Buildings construction: IMP's Research and Technological Development Fund
- Equipment and research projects: Fondo Sectorial CONACyT-SENER-Hidrocarburos

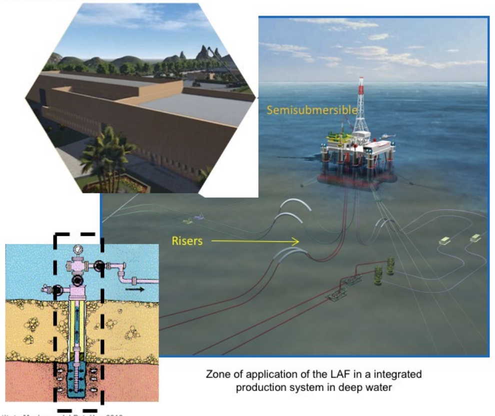
Laboratory of Drilling Fluids and Well Completion and Cementing



Laboratory of Geotechnics and Soil-Structure Interaction

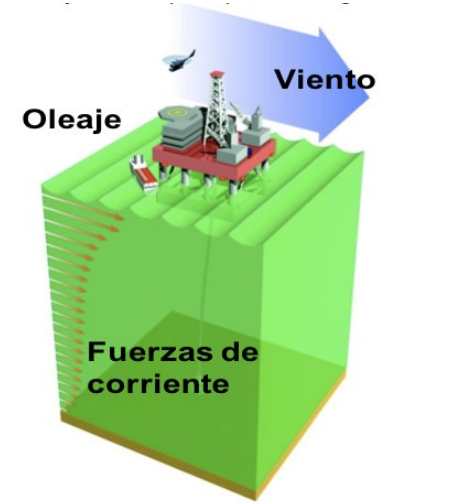


Laboratory of Flow Assurance



Zone of application of the LAF in a integrated production system in deep water

Laboratory of Numerical Simulation of Metaoceanic and Hydrodynamic Phenomena



Metocean variables with impact on the design of marine infrastructure

THANKS FOR YOUR ATTENTION

Dr. José Manuel Piña Gutiérrez
President of CiiMAR-GoMC

Dr. Porfirio Alvarez Torres
Executive Secretary
CiiMAR-GoMC

Release Dynamics of the Deepwater Horizon Accident

Scott A. Socolofsky,

A.P. and Florence Wiley Professor II

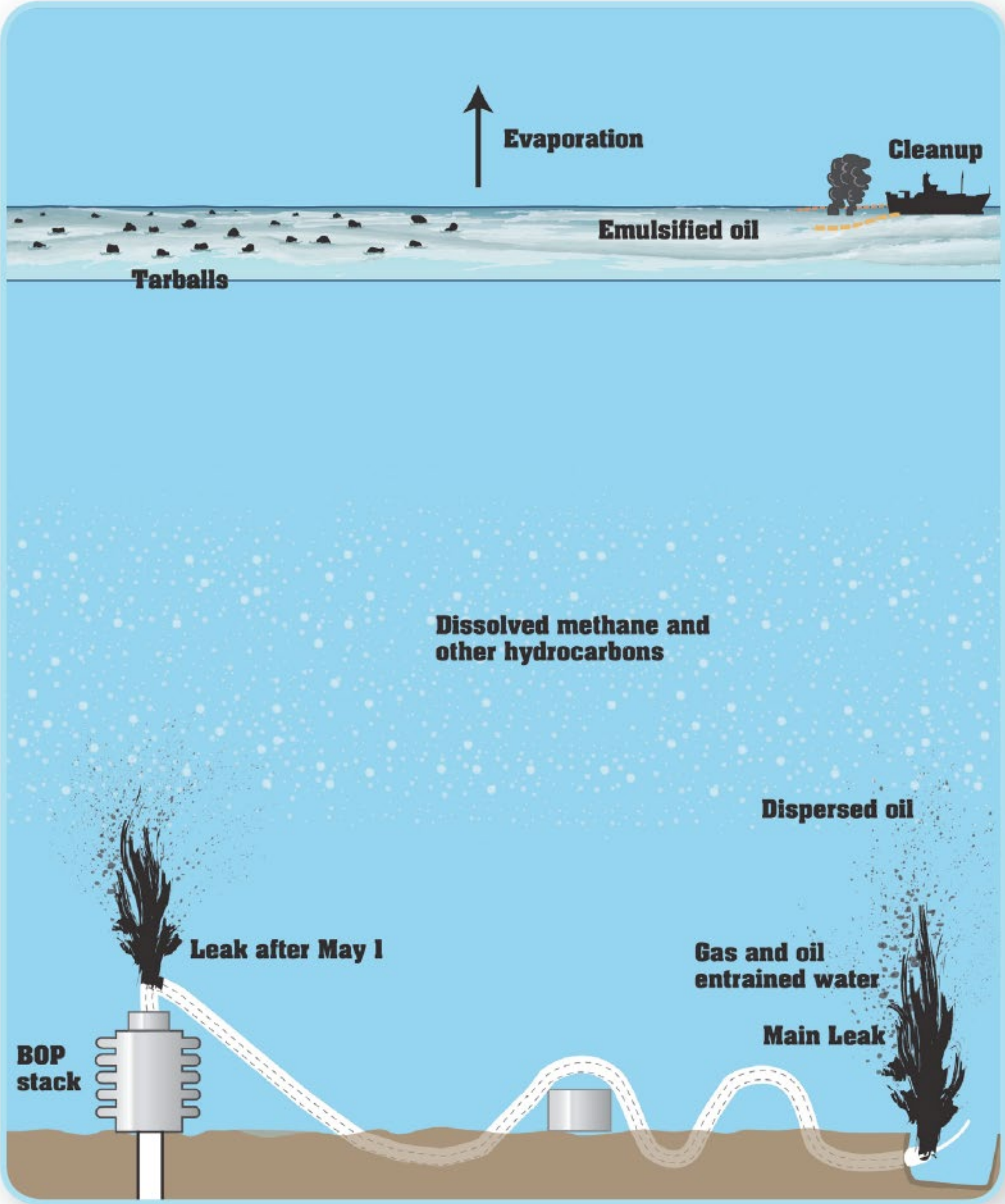
Zachry Department of Civil and Environmental Engineering

Dwight Look College of ENGINEERING
TEXAS A&M UNIVERSITY

2010 Deepwater Horizon Oil Spill

~535’000 t of oil released in the environment over 87 days at ~1500 m depth
(McNutt et al., PNAS, 2012.)

Schematic of Oil Releases from the *DWH* Oil Spill



Lehr, B., Bristol, S., and Possolo, A. (2010). "Oil Budget Calculator—Deepwater Horizon. "Federal Interagency Solutions Group, Oil Budget Calculator Science and Engineering Team. Published online at http://www.crrc.unh.edu/publications/OilBudgetCalcReport_Nov2010.pdf (as of February 1, 2011).

DWH Spill Event Timeline

Dates	Description	Collection	Subsea Dispersant Usage
4/22 – 4/28	Leak from end of broken riser	-	-
4/28 – 5/26	Release from broken riser and kink	Riser insertion tool (<5,000 bbl/d)	Highly variable use
5/26 – 5/29	Top Kill operation	-	-
5/29 – 6/3	Cutting operations	-	Consistent use, variable volumes
6/3 – 6/4	Riser flow only	-	-
6/4 – 6/6	Installation of Top Hat #4	Ramped up to ~11,000 bbl/d	Consistent use, variable volumes
6/6 – 6/13	Operation of Top Hat #4	Consistent collection at ~15,000 bbl/d	Highly variable volumes
6/13 – 7/10	Operation of Top Hat #4	Increased to ~22,000 bbl/d	Consistent use and volumes
7/10 – 7/14	Top Hat removed	~8,000 to ~16,000 bbl/d	Consistent use and volumes
7/14 – 7/15	Installation of Capping Stack and Shut in	-	-

MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 29

Dwight Look College of ENGINEERING TEXAS A&M UNIVERSITY

DWH Spill Event Timeline

Dates	Description	Collection	Subsea Dispersant Usage
4/22 – 4/28	**Leak from end of broken riser**	-	-
4/28 – 5/26	Release from broken riser and kink	Riser insertion tool (<5,000 bbl/d)	Highly variable use
5/26 – 5/29	Top Kill operation	-	-
5/29 – 6/3	Cutting operations	-	Consistent use, variable volumes
6/3 – 6/4	Riser flow only	-	-
6/4 – 6/6	Installation of Top Hat #4	Ramped up to ~11,000 bbl/d	Consistent use, variable volumes
6/6 – 6/13	Operation of Top Hat #4	Consistent collection at ~15,000 bbl/d	Highly variable volumes
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MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 29

Dwight Look College of ENGINEERING TEXAS A&M UNIVERSITY

Flow From Broken Riser

YouTube: RockyPaloma, ROV Discovers First Leaks – April 23, 2010 (4x)
YouTube: AlexThomas224, Gulf oil spill – Anything but a LEAK – Crater Plume

DWH Spill Event Timeline

Dates	Description	Collection	Subsea Dispersant Usage
4/22 – 4/28	Leak from end of broken riser	-	-
4/28 – 5/26	**Release from broken riser and kink**	**Riser insertion tool (<5,000 bbl/d)**	**Highly variable use**
5/26 – 5/29	Top Kill operation	-	-
5/29 – 6/3	Cutting operations	-	Consistent use, variable volumes
6/3 – 6/4	Riser flow only	-	-
6/4 – 6/6	Installation of Top Hat #4	Ramped up to ~11,000 bbl/d	Consistent use, variable volumes
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7/14 – 7/15	Installation of Capping Stack and Shut in	-	-

MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 29

Flow From Riser Kink Holes

YouTube: EnergyBoom1, BP Pipeline Leak – new underwater footage of the leak in the oil pipe “riser” after intervention.

DWH Spill Event Timeline

Dates	Description	Collection	Subsea Dispersant Usage
4/22 – 4/28	Leak from end of broken riser	-	-
4/28 – 5/26	Release from broken riser and kink	Riser insertion tool (<5,000 bbl/d)	Highly variable use
5/26 – 5/29	**Top Kill operation**	**-**	**-**
5/29 – 6/3	**Cutting operations**	**-**	**Consistent use, variable volumes**
6/3 – 6/4	**Riser flow only**	**-**	**-**
6/4 – 6/6	Installation of Top Hat #4	Ramped up to ~11,000 bbl/d	Consistent use, variable volumes
6/6 – 6/13	Operation of Top Hat #4	Consistent collection at ~15,000 bbl/d	Highly variable volumes
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7/10 – 7/14	Top Hat removed	~8,000 to ~16,000 bbl/d	Consistent use and volumes
7/14 – 7/15	Installation of Capping Stack and Shut in	-	-

MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 29

Flow From Cut Riser

YouTube: U.S. Department of Energy, BP Oil Spill Footage (High Def) – Leak at 4840’ – June 3 2010.

DWH Spill Event Timeline

Dates	Description	Collection	Subsea Dispersant Usage
4/22 – 4/28	Leak from end of broken riser	-	-
4/28 – 5/26	Release from broken riser and kink	Riser insertion tool (<5,000 bbl/d)	Highly variable use
5/26 – 5/29	Top Kill operation	-	-
5/29 – 6/3	Cutting operations	-	Consistent use, variable volumes
6/3 – 6/4	Riser flow only	-	-
6/4 – 6/6	**Installation of Top Hat #4**	**Ramped up to ~11,000 bbl/d**	**Consistent use, variable volumes**
6/6 – 6/13	**Operation of Top Hat #4**	**Consistent collection at ~15,000 bbl/d**	**Highly variable volumes**
6/13 – 7/10	**Operation of Top Hat #4**	**Increased to ~22,000 bbl/d**	**Consistent use and volumes**
7/10 – 7/14	Top Hat removed	~8,000 to ~16,000 bbl/d	Consistent use and volumes
7/14 – 7/15	Installation of Capping Stack and Shut in	-	-

MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 29

Installing Top Hat

YouTube: U.S. Department of Energy, BP Oil Spill Footage (High Def) – Leak at 4840' – June 3 2010.

DWH Spill Event Timeline

Dates	Description	Collection	Subsea Dispersant Usage
4/22 – 4/28	Leak from end of broken riser	-	-
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5/29 – 6/3	Cutting operations	-	Consistent use, variable volumes
6/3 – 6/4	Riser flow only	-	-
6/4 – 6/6	Installation of Top Hat #4	Ramped up to ~11,000 bbl/d	Consistent use, variable volumes
6/6 – 6/13	Operation of Top Hat #4	Consistent collection at ~15,000 bbl/d	Highly variable volumes
6/13 – 7/10	Operation of Top Hat #4	Increased to ~22,000 bbl/d	Consistent use and volumes
7/10 – 7/14	**Top Hat removed**	**~8,000 to ~16,000 bbl/d**	**Consistent use and volumes**
7/14 – 7/15	**Installation of Capping Stack and Shut in**	**-**	**-**

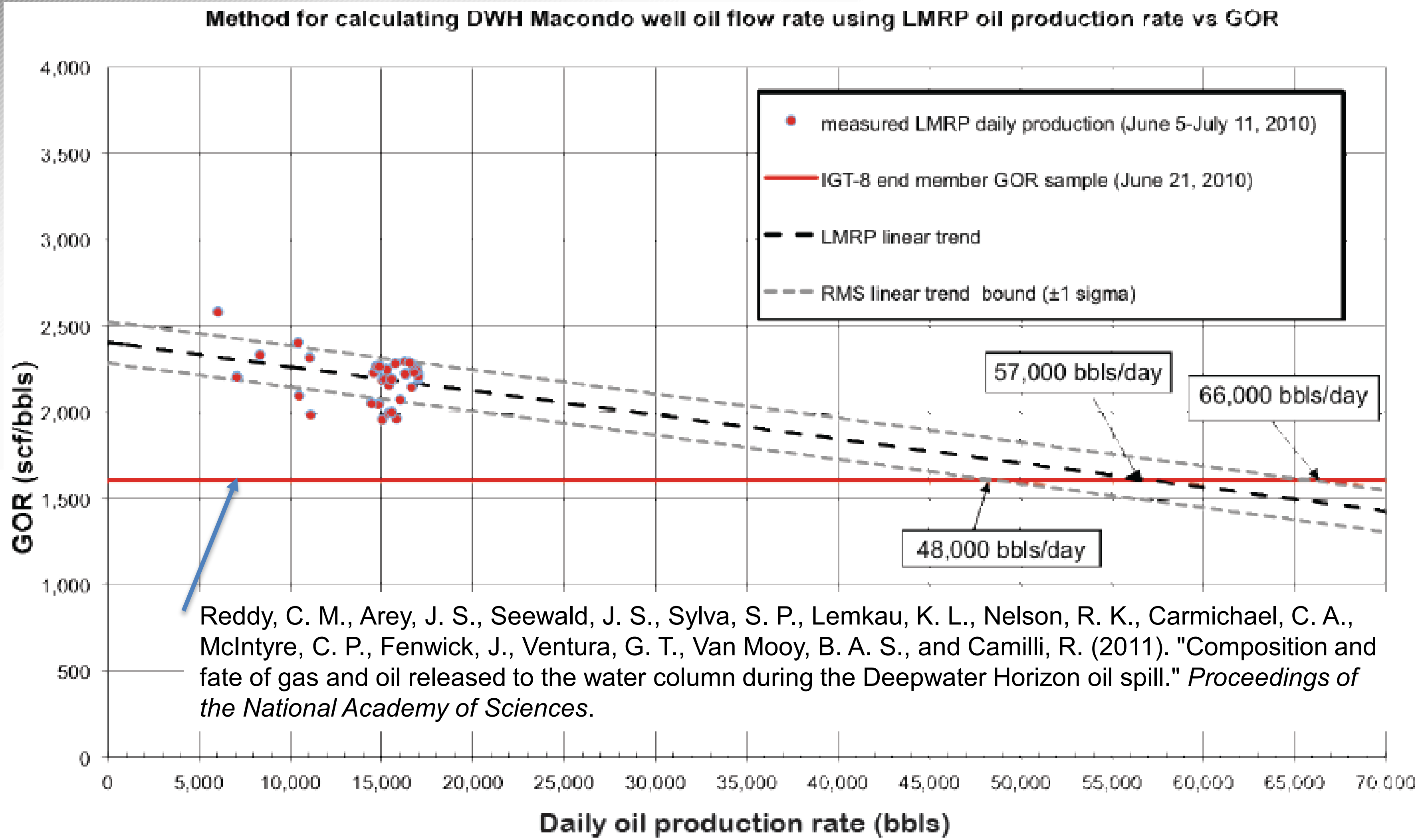
MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 29

Installing Capping Stack

YouTube: RockyPaloma, BP Oil Spill – Landing & Latching of Capping Stack (edited)

Where Could the Released Oil Go in the Ocean Watercolumn

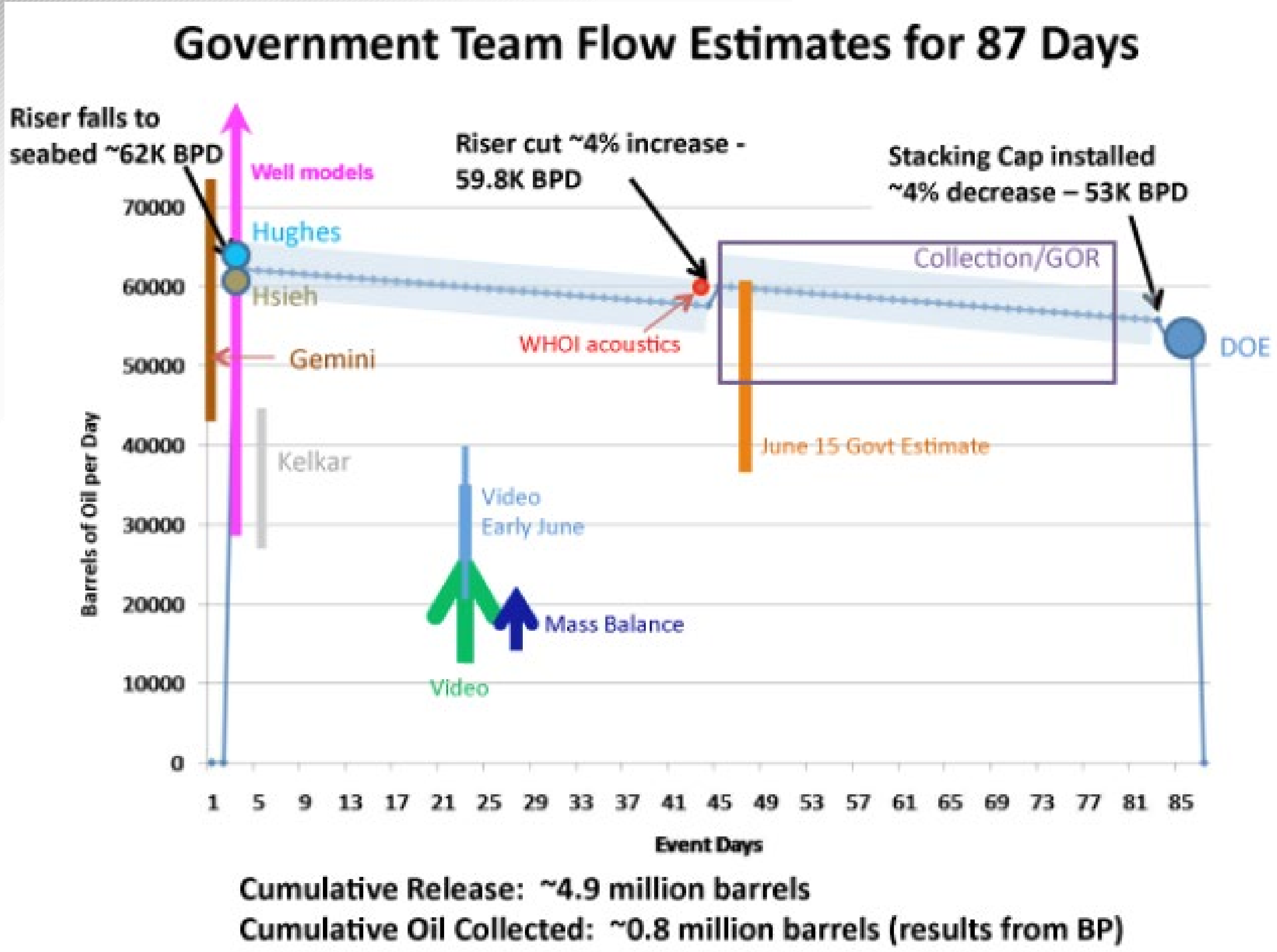
Estimation of Gas to Oil Ratio



Reddy, C. M., Arey, J. S., Seewald, J. S., Sylva, S. P., Lemkau, K. L., Nelson, R. K., Carmichael, C. A., McIntyre, C. P., Fenwick, J., Ventura, G. T., Van Mooy, B. A. S., and Camilli, R. (2011). "Composition and fate of gas and oil released to the water column during the Deepwater Horizon oil spill." *Proceedings of the National Academy of Sciences*.

McNutt, M. K., Camilli, R., Crone, T. J., Guthrie, G. D., Hsieh, P. A., Ryerson, T. B., Savas, O., and Shaffer, F. (2011). "Review of flow rate estimates of the Deepwater Horizon oil spill." *Proceedings of the National Academy of Sciences*.

Oil Release Rate from Reservoir



McNutt, M. K., Camilli, R., Crone, T. J., Guthrie, G. D., Hsieh, P. A., Ryerson, T. B., Savas, O., and Shaffer, F. (2011). "Review of flow rate estimates of the Deepwater Horizon oil spill." *Proceedings of the National Academy of Sciences*.

Total Oil Release Rate to the Environment

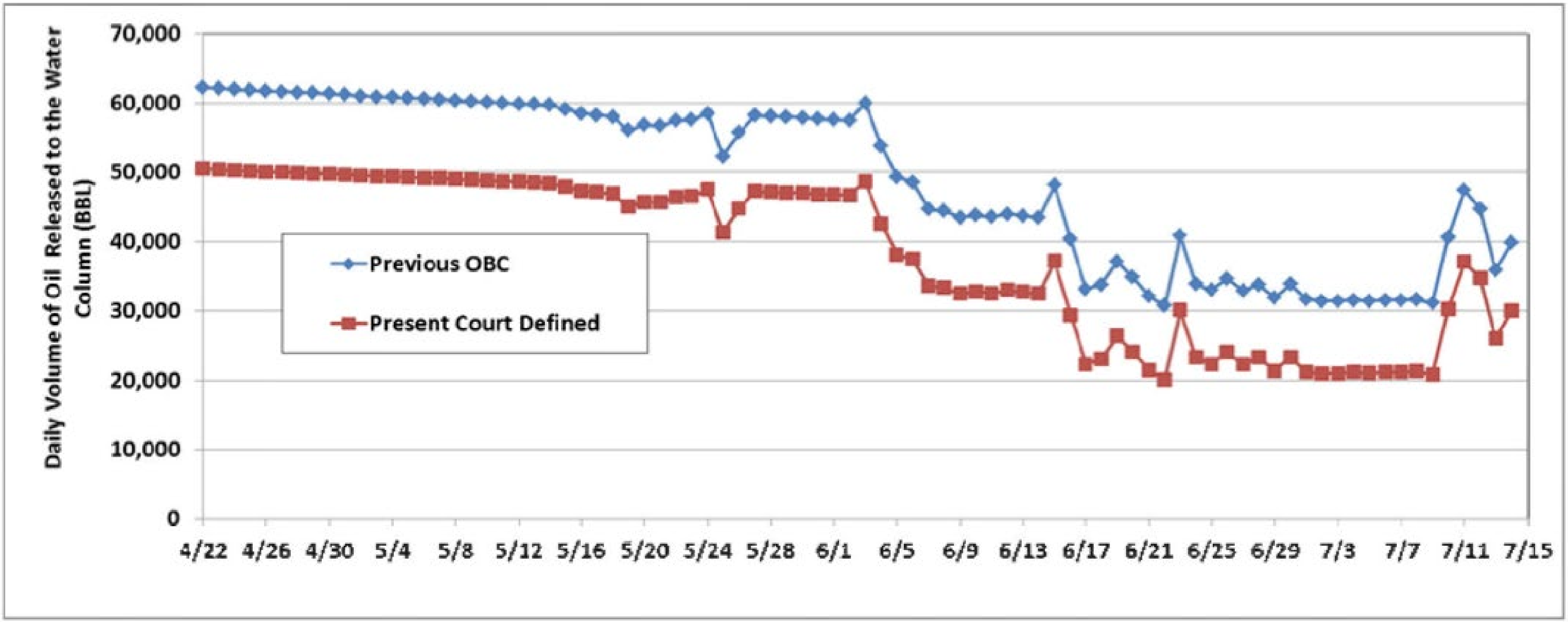


Figure 4-3. Time history of the estimated total oil release rate to the environment based on the Oil Budget Calculator (OBC) (Lehr et al. 2010) and in the present modeling analysis using the Phase II Court findings (USDC 2015) volume. All rates in barrels per day.

MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 30

Dispersant Application Rates

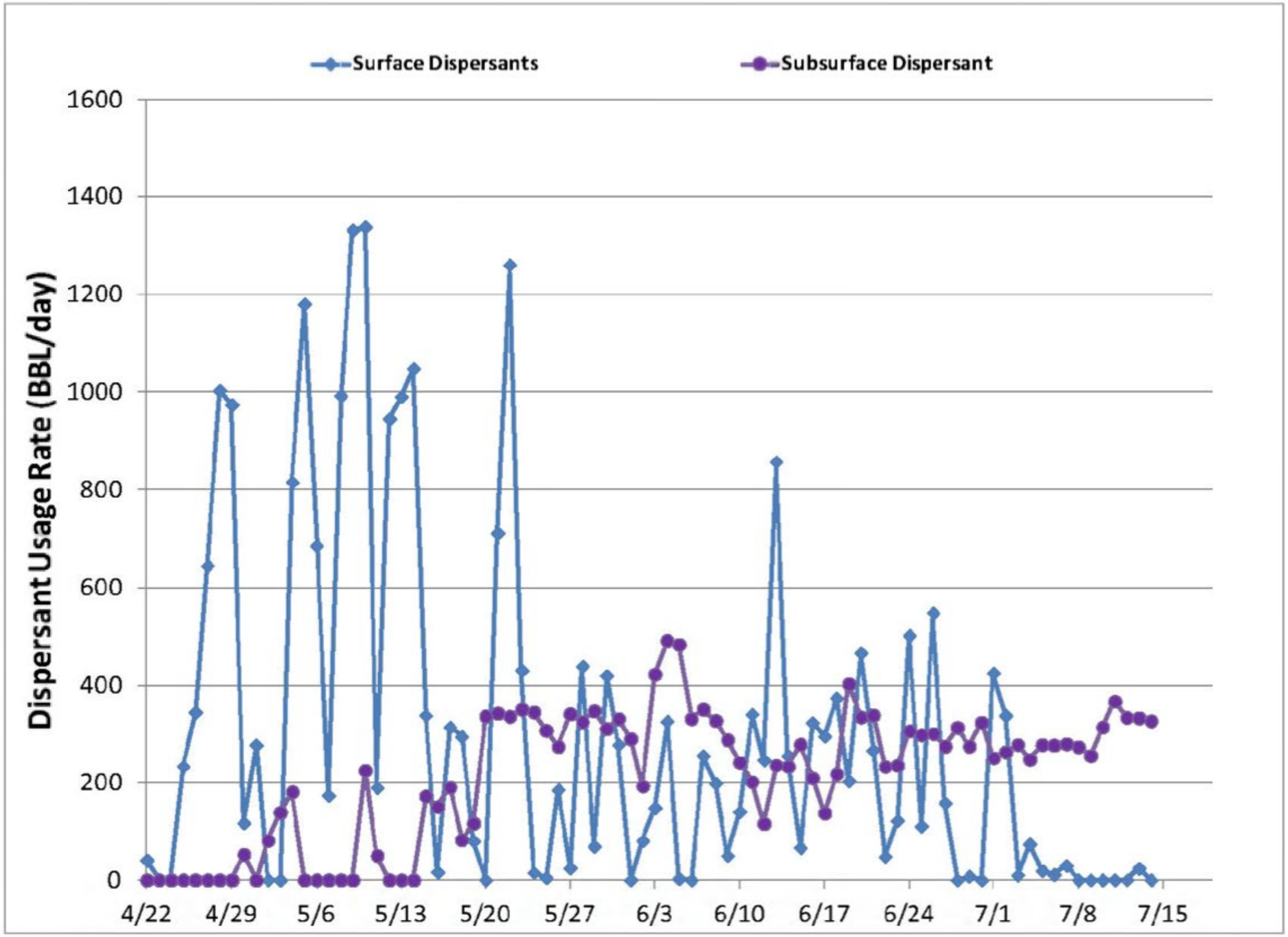


Figure 4-2. Summary of dispersant application rates from April 22 to July 15, 2010, as reported by Lehr et al. (2010).

MacKay et al. (2015) Technical Reports for DWH Water Column Injury Assessment, WC_TR.14, p. 29

Summary

- Oil flow rates in the range of 50,000 to 70,000 bbl/d, declining over period of spill (McNutt, et al. 2011)
- Total release of about 5.0 Mbbl of oil before collection (McNutt, et al. 2011)
- 0.82 Mbbl of oil collected at wellhead (Lehr, et al. 2010)
- 18,379 bbl of dispersant were injected subsea (Lehr, et al. 2010)

FATES

John W. Farrington
(Woods Hole Oceanographic Institution, USA

Julia M. Foght
University of Alberta CANADA

Research Methodology

- Field Observations at various scales.
- Laboratory Bench-scale Experiments.
- Mesocosm or Scaled-Up Laboratory Experiments.
- Modeling

FATES Research
Physical Chemical

- Evaporation
- Dissolution
- Emulsification
- Sorption–Desorption
- Deposition

FATES
Biological

- Biodegradation
- Uptake-Metabolism-Excretion
- Food Web Magnification

FATES
Deposition and Postdeposition

- To Sediments – deep water and shallow.
- Ashore – beaches and marshes

Result of Physical and Biogeochemical Processes

Evaporation, Dissolution, Photo-oxidation, Biodegradation (aerobic and anaerobic)

DWH A FEW IMPORTANT ADVANCES
Chemical and Biogeochemical

- Advances in Analytical Chemistry
  (Enabling advances in fates and effects research)

- Photochemistry/ Photo-oxidation
  - (Relevant to both Fates and Effects)

- Marine Oil Snow Sedimentation and Flocculation *(Chemistry, Biology, Physics, Geology)*

Advances in Chemistry Enabling a Better Understanding of the Fate of Oil Chemicals in the Aquatic Environment

ANALYTICAL CHEMISTRY

- Two dimensional Gas Chromatography GC x GC coupled with Mass Spectrometry.
- Fourier Transform Ion Cyclotron Resonance Mass Spectrometry (FT ICR MS).

ANALYTICAL CHEMICAL DATA

- GCxGC MS – hundreds to thousands of chemicals identified and quantified per sample.
- FT ICR MS – up to one hundred thousand or more chemicals identified and can measure relative abundance. Many can be quantified.
- Entered the realm of “Big Data”.

Oil Fates in the Coastal Area
A Quick Synopsis

- Beaches - “tar patties” and small “tar – sand” particles” persist for years.

- Marshes – long term fate – years in several places in Louisiana.

Advances in Chemistry Enabling a Better Understanding of the Fate of Oil Chemicals in the Aquatic Environment

IMPORTANCE OF

PHOTOCHEMICAL/PHOTO-OXIDATION REACTIONS

FOR THE SURFACE SLICK AND SURFACE OCEAN

(Ward and Overton, 2020)

Photo-oxidation Reactions.

- Large number of photo-oxidation chemical products confirmed by FT IRC MS Analyses.
- How do these reaction products influence dissolution, emulsification, dispersant efficacy?
- What are the fates and biological effects of the reaction products?
- Need to check previous lab and mesocosm experiments to assess influence or lack thereof of appropriate illumination.
- How do microbes interact with the photo-oxidation products?

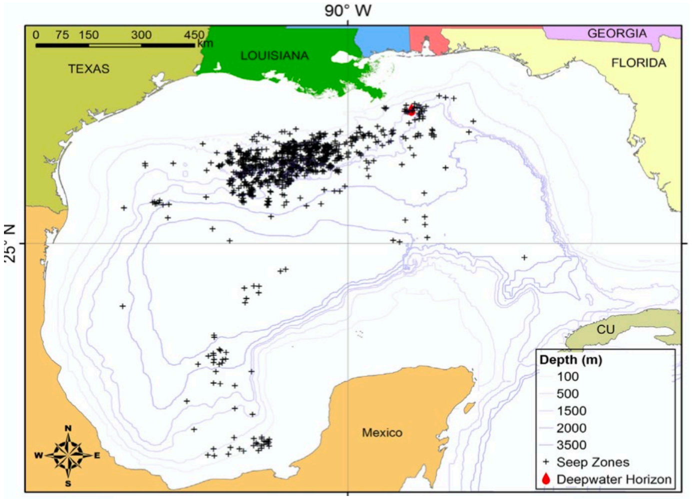
FATES: BIODEGRADATION

Early assumptions about biodegradation **potential**

- Macondo 252 Oil composition:
  - 90% of components are theoretically biodegradable
- Presence of competent microbes in GoM:
  - microbiota ‘primed’ by chronic oil exposure to gases, alkanes, BTEX, PAH
- Suitable environmental conditions:
  - temperature: 4°C to >30°C
  - site-specific limitation of nutrients, electron acceptors

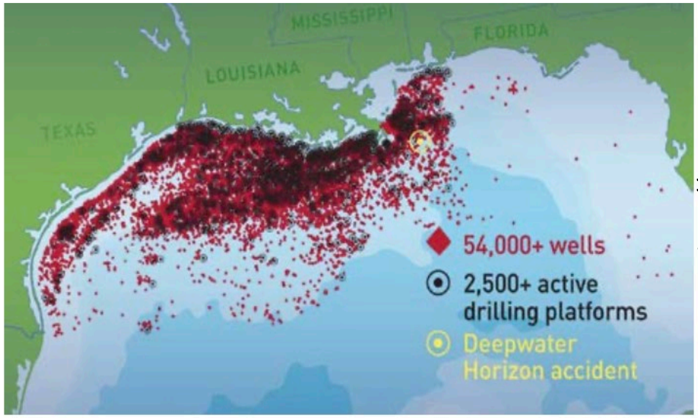
“All systems GO”

plus unprecedented opportunity to use developing **cutting-edge ‘omics and analytical techniques**



MacDonald et al. (2015) JGR Oceans

Natural hydrocarbon seeps



ECOGIG, http://ecogig.org

54,000 oil wells and 2,500 active drilling platforms

Early evidence for biodegradation

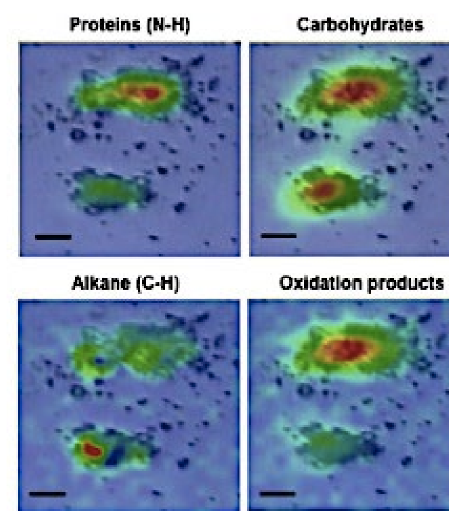
<u>Direct</u> evidence (e.g., GS-MS) **difficult to obtain**:

- abiotic factors also deplete hydrocarbons
- fresh oil is circulating

<u>Indirect</u> evidence in water column (proxies)

- Dissolved O_2 depletion in deep intrusion layers (plume)
- Microbial numbers increased slightly in plume
- PhyloChip and clone libraries (taxonomic surveys):
  - detected "blooms" of specialists and community succession
  - Enrichment of "**keystone species**"
- GeoChip (array of functional genes)
  - enrichment of known genes related to aerobic aliphatic and aromatic hydrocarbon biodegradation
- Biodegradation occurring within flocs (hotspots)

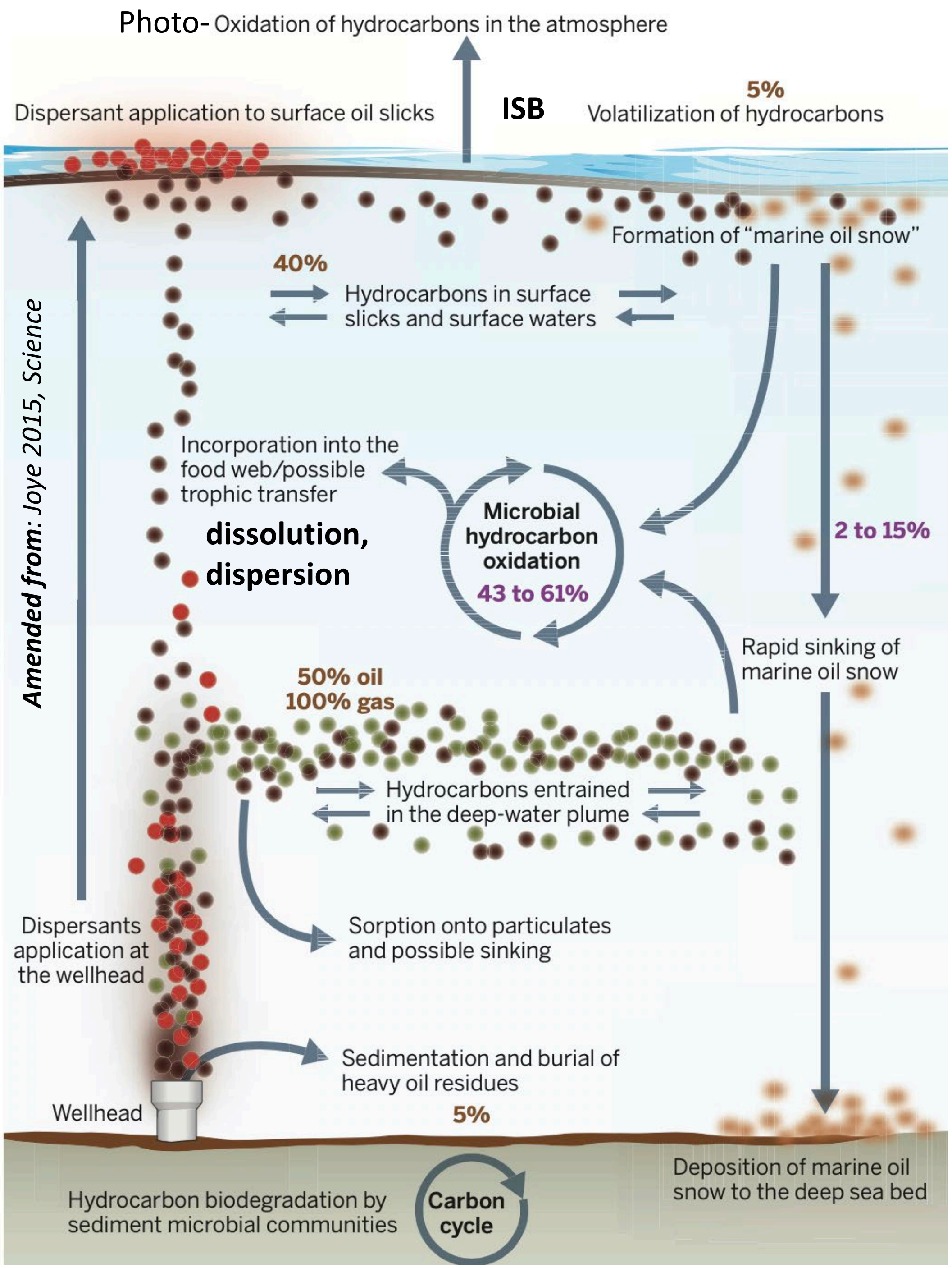
phylochip.com



Hazen, et al, 2010, Science (30:204

"Rapid and robust response to oil" *(King et al., 2015)*

Synchrotron radiation–based Fourier-transform infrared (SR-FTIR) spectromicroscopy



Spill budget uncertainty

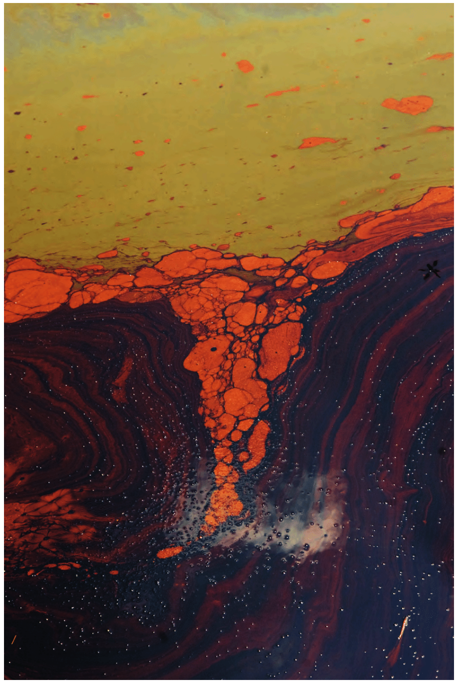
"Available data *[based on oxidation, assimilation and sedimentation]* suggest that the **long-term fate is known for only 45-76%** of discharged hydrocarbons…

The remaining hydrocarbons may have been respired in the upper regions of the ocean and deposited on coast marshes or beaches, or they may remain in Gulf waters at undetectable levels."

- Joye, 2015, *Science*

Sea surface and near-surface biodegradation

- Small proportion of oil surfaced; almost no gases
- Oil near surface was already <u>depleted in light, water-soluble components</u> (<nC_8)
- Slick rapidly <u>photooxidized</u> at surface
- Biodegradation **minimal** in slick and emulsions
  - Microbial community change
  - Detected known **species** AND **genes** associated alkane and PAH degradation
  - No bacterial 'bloom'
    - growth slowed by low nutrient [P] availability? *(Edwards et al., 2100)*
  - Bacteria-oil aggregates at edges of slicks
    - Hotspots for microbial activity



Fingas, ResearcGate

- δ^{13}C signatures indicate that Carbon from shallow oil (<33 m) entered the coastal plankton food web *(Graham et al., 2010)*

Biodegradation in deep intrusion layers

Gases: 50% consumed (?)

- Methane oxidation rates initially rapid, short-lived
  - limited by trace element availability? *(Shiller et al. 2017)*
  - 'boom and bust' for methane oxidizers (a few months of activity) *(Crespo-Medina et al., 2014)* but **potential** persisted for several years *(Bracco et al., 2020)*
- Ethane and propane were 'drivers' of microbial activity and early dO_2 consumption *(Valentine et al., 2010)*
  - may have enriched oil-degraders e,g, *Cycloclasticus* *(Rogener et al., 2018)*

Unknowns:

- Who ate the gases?
- What limited consumption?
- What is the role of pressure? (lab studies v. field studies)

Liquid oil: 30-60% biodegraded (?)

- Varying estimates of half-lives
  - days to weeks
  - slowed by dO_2 depletion in plumes
  - possibly limited by nutrient depletion
- **Hydrostatic pressure** *in situ*
  - increases water-solubility of low molecular weight hydrocarbons
  - should increase bioavailability
  - decreases microbial activity?
  - synergistic with low temperature? *(Marietou et al., 2018)*
- Microbial **community succession** observed
  - correlated with specific hydrocarbon biodegradation – "specialists" *(Bracco et al., 2020)*
- **General preference**: alkanes > aromatics > PAHs (lab and field studies)
  - opposite order of degradation in coastal waters v. offshore waters *(Doyle et al., 2020)*
  - related to pressure? To nutrients? To seeps?

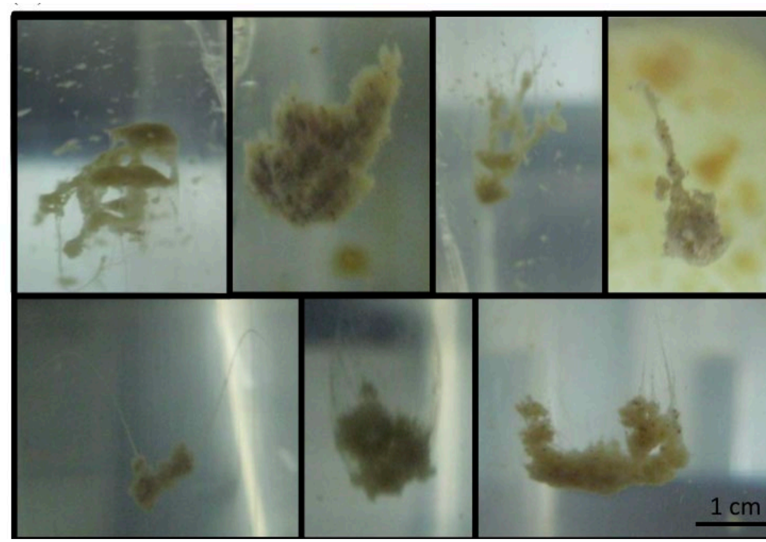
Effects of Corexit 9500A on biodegradation

- Greater surface area:volume ratio of oil droplet
  - Expect increased bioavailability, biodegradation
  - 10 μm oil droplets degraded faster than 30 μm droplets in lab study *(Brakstad et al. 2015)*
- Preferential metabolism of dispersant? *Diverse opinions*
- Inhibition of biodegradation? *(no convincing in situ evidence of this, but Corexit may affect starving bacteria; Rughoft et al. 2020)*
- **General consensus** is that dispersant **enhanced** biodegradation *in situ* *(King et al., 2015; Passow and Overton, 2021)*
- Effects on formation of Marine Oil Snow (MOS)?

Unexpected magnitude of marine oil snow (MOS) effect

MOSSFA
MARINE OIL SNOW SEDIMENTATION & FLOCCULENT ACCUMULATION

- Extracellular biopolymers (EPS, TEP)
  - sticky macroscopic flocs of minerals, sediment and microbes: marine snow
  - entrain oil to create a "**Dirty Blizzard**"
  - enhanced by particles from Mississippi R. water release and black carbon from ISB
  - effect of dispersant on MOS is 'complex'
- MOS created biodegradation hotspots during sedimentation
- Transported "**up to 30% of oil"** to deep seafloor sediments



U. Passow / Deep-Sea Research II 129 (2016) 232–240

MOSSFA "cleaned the water column but contaminated the sea floor"

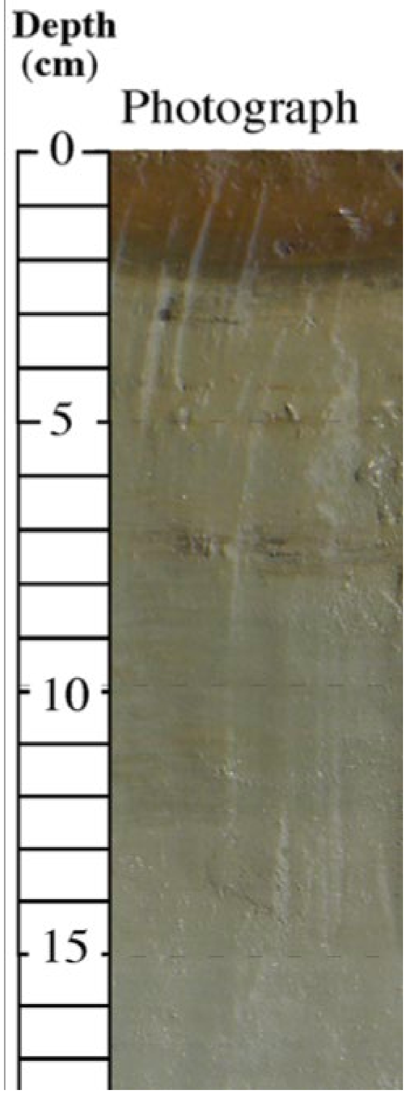
Questions about MOSSFA remain

(GoMRI MOSSFA Workshop 2018)

- Quantitative contribution to total oil biodegradation?
- Effect(s) of dispersants on MOS formation?
- Roles of photooxidation, evaporation, ISB?
- Is MOS oil more or less toxic than neat oil?
- Does oil from MOSSFA create anoxia in deep water and/or in seafloor sediments?
- Significance of MOS v. oil-mineral aggregates (OMA)?
- How to model and monitor MOSSFA?
- **Importance beyond DwH?** e.g., heavier oils, different spill types, different marine environments?

Deep-seafloor sediments and coral

- Rapid, short-lived sedimentation pulse; widespread but patchy
- Material originated near sea surface (based on gene sequences), deposited over 4-5 months *(Brooks et al., 2015)*
- Geochemically distinct sediment *(Schrope, 2013)*
    - Anaerobic layers
    - Diffusion-limited (nutrients, dO_2)
    - Different microbes, consortia
    - Slower, more selective biodegradation
    - Different pathways, different metabolites – often incomplete oxidation

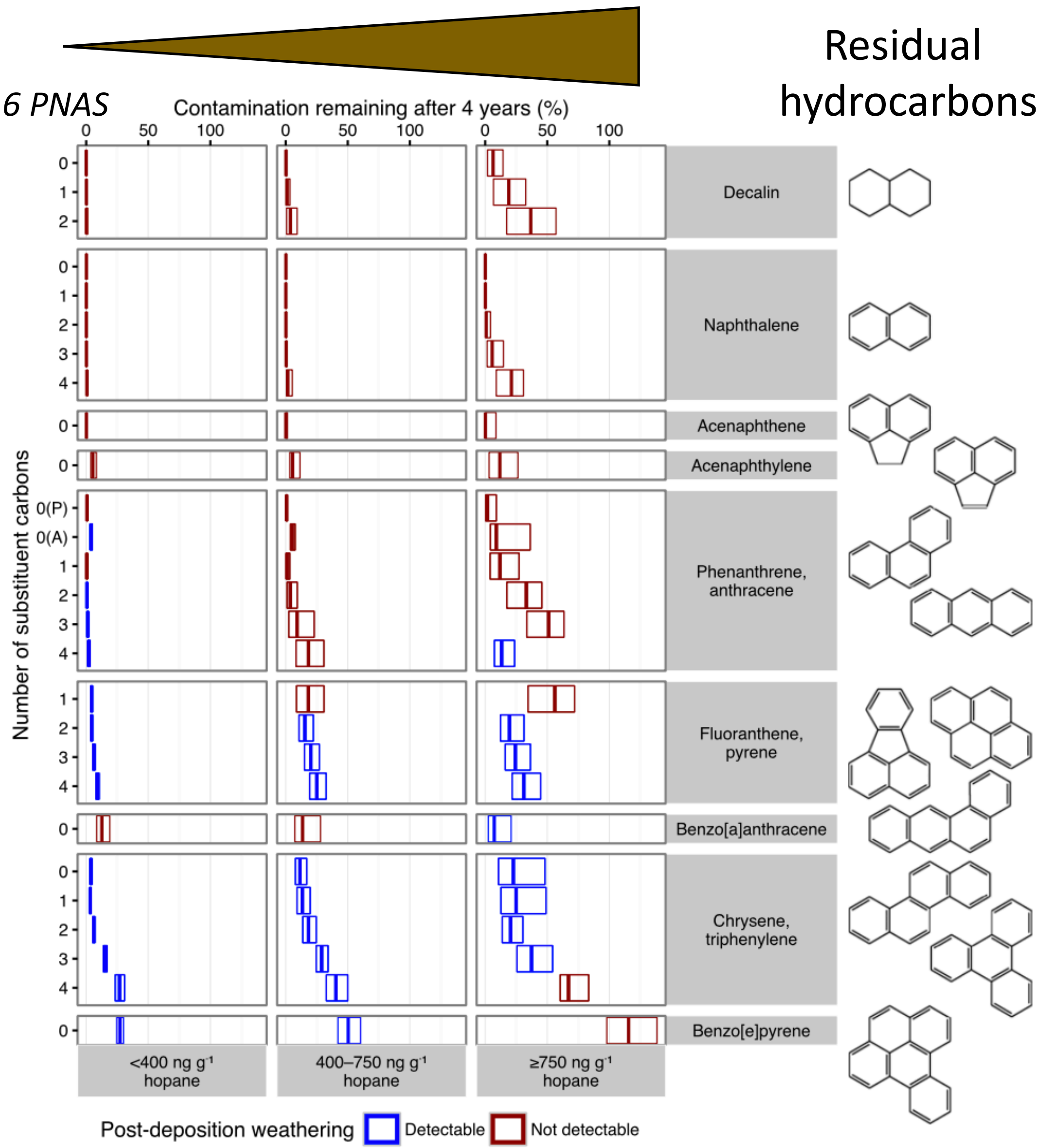


Brooks et al. (2015) PLoS ONE

Seafloor

- **Expected order** of selective biodegradation
- **Bi-phasic biodegradation** for many alkanes and PAH
    - rapid losses during sedimentation in MOS (aerobic)
    - slower losses after deposition (anaerobic)
- Longer **persistence** in highly **contaminated** sites
- Extensive **biodegradation of** several petroleum **biomarkers** including hopanes
- **ISB** contributed pyrogenic PAH to sea-floor as particulates
(Stout & Payne, 2016)

Bagby et al. 2016 PNAS



THEREFORE, multiple factors: [oil]; suspended v. buried oil; dO_2 and/or nutrient diffusion; chemical complexity

Biodegradation of stranded oil
(beaches and salt marshes)

- ~ 10-30% of surface oil impacted coasts after May 2010
  - already weathered and photooxidized; continued transformation
- Biodegradation observed: *(Kujawinski et al. 2020; Beazley et al. 2012)*
  - In sandy beaches – rapid bloom of bacterial communities
  - In ‘tar balls’ and ‘tar patties’ – slow biodegradation *(Bociu et al. 2019)*
  - Oxygenated hydrocarbon residues accumulate *(White et al. 2016)* but may be amendable to biodegradation *(Harriman et al. 2017)*
  - Non-porous shoreline sediments – slow anaerobic biodegradation
- Site-specific:
  - well-aerated, porous, sandy beaches: half-life of oil <4 weeks
  - Buried oil persists and still re-mobilizes 10 years later
  - saltmarshes especially with grasses (rhizosphere microbes?)

Take-home messages re: Oil Fates

- Photooxidation was more important than expected
- Subsurface dispersant likely enhanced biodegradation
- Scale of MOSSFA ‘pulse’ was unexpected – enhanced biodegradation AND transport to seafloor
- Residual oil concentrations vary by ecosystem:
    - below detection in water column within weeks;
    - remained in seafloor sediment traps for several years;
    - still detectable in some marshes and on seafloor 10 years on
- Unprecedented application of novel technologies: analytical chemistry, ‘omics and databases
- Enormous interdisciplinary opportunity & long-term $$
- **Caveats**: *in situ* v. *ex situ* experiments; relevant conditions; baseline data for comparison; extrapolation from GoM to other spills

Deepwater Horizon Oil Spill – Effects Part II

Nancy N. Rabalais
Louisiana State University

March 11, 2021
Open Committee Meeting

Photo: Christopher Berkey

What is an Effect?

- Controlled experiment in laboratory or micro- or mesocosms
- Before-and-after controlled experiments with exposure versus inferential observations
- Samples, collections that differ ‘before,’ ‘during’ and ‘after’ the spill do not necessarily identify an ‘effect.’
- The sequence of events for the formation and maintenance of bottom-water hypoxia (‘Dead Zone’) on the Louisiana shelf in 2010 was similar for 24 preceding years and 2 post-spill years. There was no evidence that DWH oil residues affected the typical seasonal development of bottom-water hypoxia in 2010. (Rabalais et al. 2018)
- Limited extrapolation between laboratory and mesocosm studies to in situ populations, communities, and long-term effects

Why is it Difficult to Identify an Effect?

- Lack of baseline and long-term data
- Unknown exposure over time
- Inappropriate experimental design
- An ‘open’ ecosystem
- Effects of multiple stressors
- Inter-specific interactions
- Placed within a long-term or random cycle of indirect effects
- Shifting baselines

Gulf of Mexico Offshore

- The 2010 shelf phytoplankton community composition differed from the longer-term data. Some shifts were lower abundance for some phytoplankton groups and higher abundance for other groups. (Parsons et al. 2015)

- Inconsistent with laboratory studies for which cultured phytoplankton were exposed to a Macondo surrogate oil using the water accommodated fraction (WAF), and dispersed oil using a chemically enhanced WAF (CEWAF) and diluted CEWAF. A range of responses—no response, reduced growth rates longer lag time to exposure, some or no inhibition of photosynthetic efficiency, species dependent. (Bretherton et al. 2018, Ozhan and Bargu 2014) May be lethal or affect food webs (inference).

- Zooplankton from near-surface waters where floating oil was prevalent showed evidence of exposure to Macondo well oil. Mesozooplankton tissues contained higher concentrations and characteristics of PAHs indicative of a liquid fossil fuel source. (Mitra et al. 2012)

- Concentrations of PAHs that buoyant fish embryos might realistically experience (1-15 ppb) caused dose-dependent defects in heart function in larval yellowfin tuna, southern bluefin tuna and yellow tail amberjack.

- Similar effects on pericardial and yoke sack edema in mahi-mahi (dolphinfish) were found in experimental exposures to water-accommodated Macondo oil skimmed from the water surface. (Mager et al. 2014).

Gulf of Mexico Offshore

- Despite over seven decades of production and hundreds of oil spills per year, there were no comprehensive baselines for petroleum contamination in the Gulf of Mexico.

- Gulf-wide fish surveys extended over seven years (2011–2018). A total of 2,503 fishes, comprised of 91 species, were sampled from 359 locations and evaluated for biliary polycyclic aromatic hydrocarbon (PAH) concentrations.

- The northern GoM fishes had significantly higher total biliary PAH concentrations than the West Florida Shelf, and coastal regions off Mexico and Cuba. The highest concentrations of biliary PAH metabolites occurred in yellowfin tuna, golden tilefish, and red drum.

- Conversely, biliary PAH concentrations were relatively low for most other species including economically important snappers and groupers.

- While oil contamination in most demersal species in the north central GoM declined in the first few years following DWH, more recent increases in exposure to PAHs in some species suggest a complex interaction between multiple input sources and possible re-suspension or bioturbation of oil-contaminated sediments (inference). (Pulster et al. 2020)

Gulf of Mexico Offshore

- Concentrations of methane measured in the plume were as high as 3 parts per million (180 $\mu M\ l^{-1}$), tens of thousands of times higher than background levels. The oil plume extended 500 km to NE and SW of the source. (Crespo-Medina et al. 2014).

- The telltale indicator of biodegradation of hydrocarbons in the deep-sea plume was the occurrence of anomalously low levels of dissolved oxygen (but not debilitating, inference) at the depths of the plume detectable as far as 560 km from the Macondo well.

- Flocculating mucus with the degrading bacteria formed MOSFFA (Marine Oil Snow Sedimentation and Flocculent Accumulation) that settled to the bottom exposing benthic communities. (Kessler et al. 2011)

- In September-October 2010 the most heavily oil-impacted sediments were enriched in bacteria species with genetic sequences very similar to bacteria in the deep-sea hydrocarbon plume. (Mason et al. 2014)

- Activated genes indicated that bacteria were actively degrading hydrocarbons, including lower molecular weight aromatic hydrocarbons. PAHs in the sediments were not being degraded as rapidly, presenting longer-term contaminant exposure. (Scott et al. 2014)

- Microbial communities in sediments impacted by the DWH spill had returned to near baseline conditions after two years. (Overholt et al. 2018)

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Benthic Communities

- Photographic observations of larger bottom-dwelling animals (invertebrates and fishes) during August and September 2010 revealed very few species in areas close to the wellhead and carcasses of sea cucumbers and sea pens were observed nearby. Remains of pelagic tunicates littered the bottom, likely casualties of the blowout and MOSSFA. (Valentine and Benfield 2013)
- Macrofauna and meiofauna (> 0.3 mm and > 63 μm, respectively) were collected 2–3 months after the Macondo well was capped (Montagna et al. 2013).
- The most severe relative reduction of faunal abundance and diversity extended to 3 km from the wellhead in all directions covering an area about 24 km^2.
- Moderate impacts were observed up to 17 km towards the southwest and 8.5 km towards the northeast of the wellhead, covering an area 148 km^2.
- Low diversity, low evenness, low taxonomic richness of the infauna communities affected both sizes, and high nematode to copepod ratios corroborated the severe disturbance of meiofaunal communities.
- Benthic effects were correlated to total petroleum hydrocarbon, polycyclic aromatic hydrocarbons, and barium concentrations, and distance to the wellhead.
- The areal extent of impacts was refined to 263 km^2 with the additional samples analyzed. (Reuscher et al. 2020)

Longer-Lived Biogenic Habitats

- Sackett Bank, 270 kilometers to the west of the Macondo site, was not in the areas most heavily and persistently oiled, but the location was subjected to intermittent exposure from mid-May through August of 2010. Calcareous rhodoliths collected from the bank in December 2010 smelled conspicuously of petroleum (less so on a return to the site in April 2011). In this case, there were several community surveys conducted before and after the DWH oil spill.

- The diversity of seaweeds and decapod crustaceans associated with rhodoliths on deep offshore banks in the northwestern Gulf of Mexico decreased dramatically after the Macondo blowout. (Felder et al. 2014)

- Unconsolidated rubble and rhodoliths dredged at depths of 55–75 m appeared either bleached and mostly denuded of fleshy algae or sparsely covered by a few crust-forming species (figure 2). Pre-spill species richness of 60 compared to post-spill surveys with species richness of 10.

- Decapod crustacean communities declined in both abundance and diversity and exhibited major shifts in species dominance.

- The calcareous habitat is somewhat self-regenerative; rhodoliths appear to serve as seedbanks for biological diversity because dead rhodolith rubble became covered by epi- and endolithic algae and microbes in laboratory microcosms.

Longer-Lived Biogenic Habitats

- At locations ranging from 200 to more than 2000 meters along the continental slope of the northern Gulf of Mexico, hard carbonate substrates were exposed to oil on the otherwise sediment-covered seafloor. A unique fauna is associated with the soft and hard corals.
- In November 2010, four months after the Macondo well was capped, corals inhabiting hard substrates at 1,370 meters depth and 11 kilometers from the wellhead were observed to be covered by brown flocculent material.
- Coral colonies exhibited varying degrees of tissue loss, enlargement of hardened body parts, and excess mucus production.
- Associated fauna that lived commensally on the coral colonies were injured.
- Analysis of petroleum biomarkers in the flocculent material was consistent with those from the deep hydrocarbon plume from the Macondo well. (White et al. 2012)
- Two additional sites surveyed in November 2011 indicated clear signs of impact on coral colonies. These sites were 11 km to the south of the wellhead at 1560 m and the other at 22 km away in 1850 to 1950 m. (Fisher et al. 2014)
- Recovery rates in the deep sea are likely to be slow, on the order of decades or longer. (inference)

Marsh Environments

Photos: R.E. Turner and Coastal Waters Consortium

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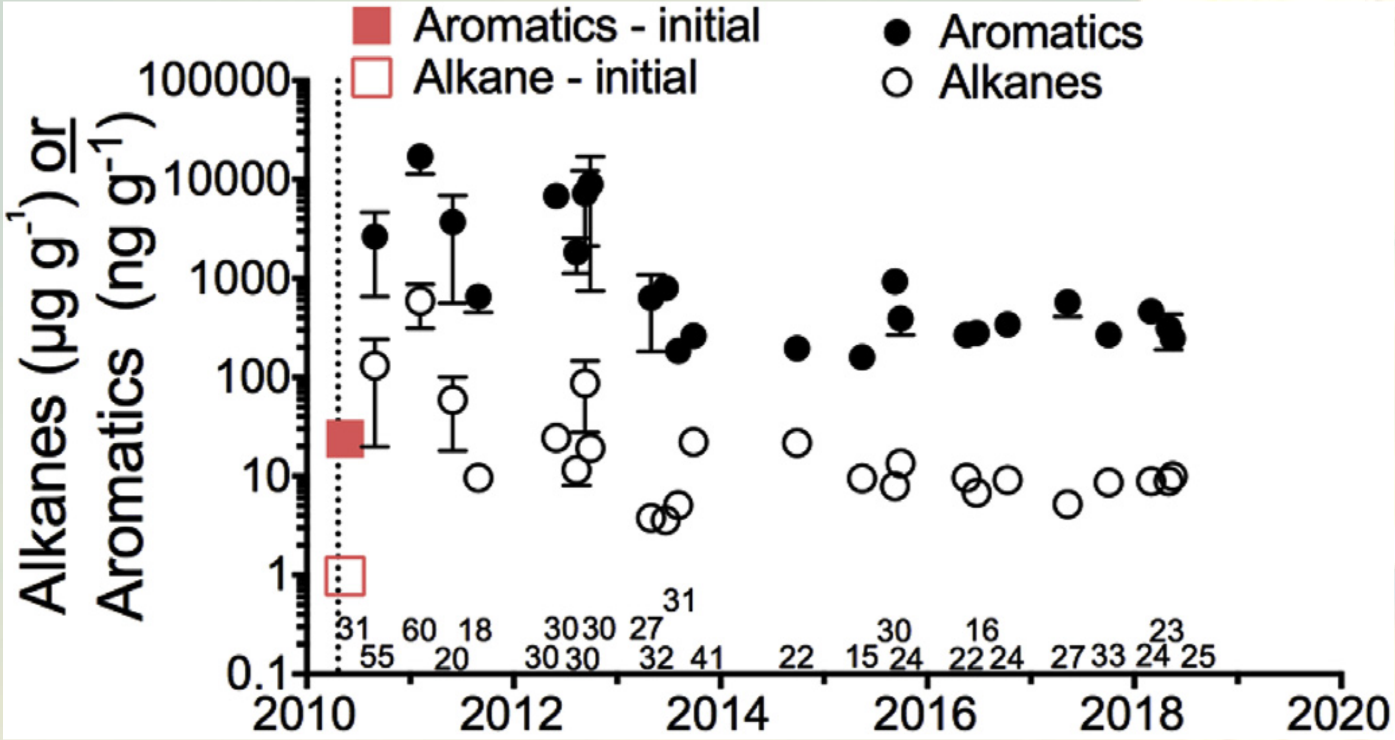
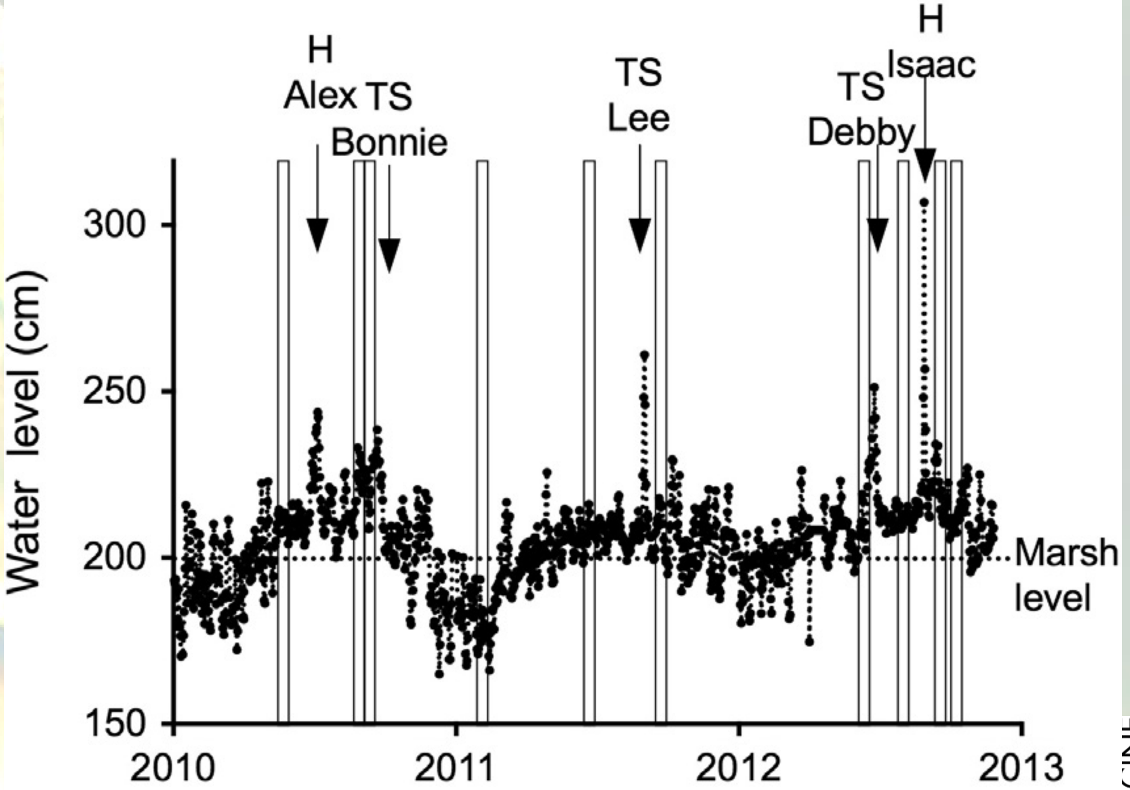
Marsh Environments



Turner et al. 2019



Turner et al. 2014

Pre-Spill

Immediate Post-Spill

Gulf of Mexico Research Institute

Sediment Microbial Communities

- Subtidal sediment bacterial communities from 16S rRNA gene surveys at 11 sites in southern Louisiana before the oil spill were resampled three to four times over 38 months after the spill. (Engel et al. 2017)

- Hydrocarbon biomarkers indicated that oil replaced native natural organic matter originating from *Spartina* and phytoplankton in the marshes between May 2010 and September 2010.

- The major shift occurred within the first four months, but another community shift in class- and order-level microbes occurred at the time of peak oiling in 2011.

- Two years later, hydrocarbon levels decreased and bacterial communities became more diverse. The diversity of the microbial community was significantly lower with increasing total petroleum hydrocarbon (TPH) concentrations in the top 2 cm of sediments, dropping from a Shannon diversity Index of 5 to 1.5 when TPH concentrations increased from 10,000 mg kg^{-1} to 10,000–500,000 mg kg^{-1}. (Atlas et al. 2015)

- The microbial community diversity increased over time until it approached that of unoiled reference sites in Bay Jimmy (upper and eastern Barataria Bay, Louisiana. (Atlas et al. 2015)

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Marsh Erosion

- Heavily-oiled marsh shorelines eroded at a faster rate than those moderately- or lightly-oiled.
- Emergent vegetation seldom re-established after oiling. Eroded marshes are forever. You cannot ‘see’ an effect on a missing marsh. (McClenachan et al. 2013, Turner et al. 2016)
- The marsh loss from oiling is additive to the negative effects of other human and natural processes contributing to coastal erosion (42.9 km^2 yr^{-1} from 1985 to 2010). (Couvillion et al. 2011)
- Measurements of shoreline erosion, soil strength, percent vegetation cover, sediment PAH concentrations, and marsh overhang began in November 2010 at 30 sites along a shoreline that ranged from ‘low’ oil (<200 $\mu g\ kg^{-1}$ PAHs; most without the Macondo oil chemical signature) to ‘high’ oil (>20,000 $\mu g\ kg^{-1}$), all with the Macondo oil chemical signature.
- Marsh overhang for the high oil sites was significantly greater than for the low oil sites.
- Soil shear strength was similar in the upper 50 cm of both high and low oil sites, but the shear strength was much lower below 60 cm in the high oil sites than in those with low oil.
- There were no significant differences in the percent *Spartina* vegetation cover for four of five sampling periods.
- After then, the erosion increased at the low oil sites as the promontories created by erosion of adjacent oiled sites left them exposed to wave action. (McClenachan et al. 2013)

Marsh Environments

- Early assessments clearly documented the dieback of all marsh vegetation in heavily oiled areas in July 2010 in the form of no living vegetation and the presence of dead stems layering the exposed, oiled sediments. (Lin and Mendelssohn 2012, Silliman et al. 2012, Zengel et al. 2015)

- Vegetation cover after 7 to 16 mo remained much lower than in the control sites. (Silliman et al. 2012, Lin and Mendelssohn 2012, respectively)

- The average live aboveground biomass of *Spartina* and *Juncus* combined was significantly lower, almost none, in the heavily oiled marsh compared to the reference marsh, but there was no significant difference between the combined weight of the two in the moderately oiled marsh and the reference marsh.

- The live *Spartina* aboveground biomass and stem density was about 10 times greater than for *Juncus* in the moderately oiled marsh.

- Manual treatment of oiled marshes resulted in greater vegetation cover than mechanical treatment and no treatment, at least through one year. Reference marshes had a much higher percent vegetation cover than either treated or untreated marshes for more than two years after the initial oiling. (Zengel et al. 2015)

- Vegetation recovery was quicker with planting than with no planting, and shoreline retreat was reduced where there was planting.

Longer-Term Marsh Studies

- All metrics indicated initial impacts from oiling and most showed recovery timeframes of several years or more for *Spartina alterniflora.*
- *Spartina* stem density was the exception, with more rapid recovery due to possible stimulation by unoccupied space and perhaps residual oiling (inference); however, increased stem density was not leading to comparable increases in cover or biomass.
- In contrast with *Spartina*, *Juncus* was impacted to a greater degree across all metrics, with much slower recovery or lack thereof.
- In comparison to the marsh edge, the oiled marsh interior tended to have a lesser degree of impacts, at least initially, but, impacts were still detected in the interior and recovery often tracked similarly to the marsh edge.
- Complete vegetation recovery was not observed, especially for marshes with a *Juncus* component and for belowground biomass (Zengel et al. GoMOSES 2019, ms in review)
- There was a sequence of recovery of aspects of marsh ecosystems that were necessary for subsequent component recovery.

Marsh Epifauna

- For **fiddler crabs**, abundance and burrow diameter (as an indicator of crab size) declined, and the proportion of two co-inhabiting species occurred following oiling. A return to the ‘reference” abundances (reduced by 39% following oil exposure) was not complete by 2014.
- The burrow diameter returned to pre-spill size by 2012. The proportion of *Uca spinicarpa* surpassed that of *U. longisignalis* because of less-vegetated areas with clay soils increased. Return to reference species composition will likely follow the re-vegetation of *S. alterniflora* in damaged areas (inference).
- Results from **periwinkle** surveys indicated significant losses of periwinkles in oiled habitat and also a continuing slow recovery in snail abundance and size distribution related to habitat recovery. (Zengel et al. 2016)
- With longer-term data, neither density nor population size structure of periwinkles recovered at heavily oiled sites after 9 y where snails were smaller and more variable in size structure.
- Total aboveground live plant biomass and stem density remained lower over time in heavily oiled marshes. Periwinkle population recovery may take one to two decades after the oil spill at moderately oiled and heavily oiled sites, respectively (inference). (Deis et al 2020)
- Predator-prey interactions among **juvenile blue crabs** and periwinkles and marsh fish movements were altered as determined by prior oil exposure of either predators or prey (Robinson and Rabalais 2019, Martin et al. 2020)

Marsh Infaunal Organisms

- The meiofauna were severely damaged along with *Spartina* in heavily oiled areas where TPH concentrations ranged from 50 TPH g^{-1} to 500 mg TPH g^{-1} sediment compared to reference marsh levels of ~0.3 TPH g^{-1} sediment.

- Meiofauna recovery followed the time courses of *Spartina* recovery and TPH degradation, with substantial recovery of many organisms within 36 months of the spill, while polychaetes, ostracods, and kinorhynchs had still not recovered to background levels in reference marshes 48 months after the spill. (Fleeger et al. 2015)

- A community of 12 abundant taxa of meiofauna and juvenile macroinfauna began to rebound from oiling in < 2 years, but did not fully recover after 6.5 years. The pace and intensity of recovery of nematodes, copepods, most polychaetes, tanaids, juvenile bivalves, and amphipods were significantly and positively related to the recovery of *Spartina* and benthic microalgae. (Fleeger et al. 2020)

- However, total petroleum hydrocarbon concentrations remained elevated over time, and live belowground plant biomass, bulk density, dead aboveground plant biomass, and live aboveground biomass of *Juncus* were not resilient. Recovery of a kinorhynch, a polychaete, ostracods, and juvenile gastropods was suppressed in association with these factors. (Fleeger et al. 2020)

Marsh Insects

- Studies of the horse fly (a top predator insect in marsh food webs) biweekly in oiled and unaffected locations from immediately after the oil spill in June 2010 until October 2011. The abundance of horse flies crashed in oiled areas in 2010. (Husseneder et al. 2016)

- The genetic makeup of six of seven oiled populations indicated few breeding parents, reduced effective population size, a lower number of family clusters, and fewer migrants among populations. The beauty of the experimental design is that it ranged from genetics to population levels on a keystone insect species with consistent oiled and unoiled results.

- Overall abundances of the terrestrial arthropod community in oiled and unoiled *Spartina* marsh transects was suppressed by 50% at oiled sites in 2010, but had largely recovered in 2011. Subguilds of predators, sucking herbivores, stem-boring herbivores, parasitoids, and detritivores all tended to be suppressed at oiled sites by 25% to 50% in 2010 and recovered by 2011. (Pennings and McCall 2016)

- Comparisons of insects from three lightly-oiled and four heavily-oiled sites in Barataria Bay and from three unoiled reference sites in Delacroix, Louisiana, were used to determine the impacts of the distribution and re-distribution of Deepwater Horizon (DWH) oil on these saltmarsh ecosystems. A total of 9,476 and 12,256 insects were collected in 2013 and 2014, respectively. The terrestrial arthropods were negatively affected by the re-distribution of DWH oil by Hurricane Isaac in 2012, although the level of impacts varied among the arthropod groups. The mean diversity index was higher (>1.5) in 2014 than in 2013. (Bam et al. 2018)

Marsh Nekton

- Marsh killifish exposed to initial heavy oiling in the field and a range of exposure experiments displayed genetic abnormalities. (Whitehead et al. 2012)

- Field collections of marsh and seagrass nekton, however, did not reveal any effects of oil exposure on population dynamics. The mostly consistent results showed little evidence of any influence from potential Macondo oil exposure. (Fodrie and Heck 2011, Fodrie et al. 2014, Able et al., 2015)

- There were no statistical differences in resident marsh killifish in oiled and unoiled Louisiana marshes in 2012 and 2013 nor by marsh edge, pond, or creek microhabitats; there were no total nekton- or species-specific differences between oiled and unoiled subhabitats. (Able et al. 2015, Fodrie et al. 2014)

- A pre-spill study on seagrass beds from the Chandeleur Islands, Louisiana, to St. Joseph's Bay, Florida (all along oiled shorelines) in June-September of 2006-2009 and again in 2010 during peak oiling. There were no statistical differences among the four pre-spill years and the year of the spill for total fishes caught across geographic areas. (Fodrie and Heck 2011, Moody et al. 2013)

Marsh Nekton….more

- Killifish collected at Grand Terre in lower Barataria Bay, near marshes that had been heavily oiled, had elevated CYP1A gene expression, indicating a response to PAHs in their livers. Killifish collected at unoiled sites along the Mississippi and Alabama coasts did not have elevated CYP1A gene expression. (Whitehead et al. 2012)

- A year after oil reached marshes in Bay Jimmy in Barataria Bay (a heavily oiled area), the growth rates of brown shrimp deployed in cages near heavily and moderately oiled marshes were less than half those near unoiled and lightly oiled marshes. Growth rates of brown shrimp were negatively correlated with the concentration of PAHs in bottom sediments, which averaged about 600 ppb near oiled marshes. (Rozas et al. 2014)

Marsh Vertebrates – Resident Seaside Sparrows

- Seaside sparrow nesting data from 2012 and 2013 (two and three years post marsh oiling) indicate that nests on unoiled sites were significantly more likely to fledge than those on oiled sites. (Bergeon Burns et al. 2014)
- Sparrows in areas with higher PAHs in sediments had elevated CYP1A gene expression, indicating metabolism of ingested oil.
- Microarray - 2011 sparrows: ~ 270 genes affected – genes associated with DNA damage and cell death (Bonisoli-Alquati et al. 2020) Transcriptomic response in the liver of Seaside Sparrows exposed to DWH oil compared with birds from a control site.
- Broad range of toxic effects of Macondo oil on Seaside Sparrows. 295 genes differentially expressed between birds exposed to oil and controls.
- The identified genes were involved in a coordinated response that promoted hepatocellular proliferation and liver regeneration while inhibiting apoptosis, necrosis, and liver steatosis.
- Alteration of genes regulating energy homeostasis, including carbohydrate metabolism and gluconeogenesis, and the biosynthesis, transport and metabolism of lipids,
- These genetic analyses provide molecular mechanisms for the long-standing observation of hepatic hypertrophy and altered lipid biosynthesis and transport in birds exposed to crude oil.

Recommendations for Future Spills (Effects) (Position of author of ppt, not NASEM)

- Despite attempts for coordination, the beginning and later investigations were not compatible for exposure or degree of oil degradation.
- There were considerable overlaps in types of studies.
- Measurements be coordinated, SOPs, level of quantitative analytics.
- With enough lead time, e.g., DWH, set up experimental plots for pre-spill conditions, pelagic and shoreline
- Adequate search for applicable long-term data
- Toxicity studies conducted on organisms in a more ‘realistic’ habitat.
- Coordination of effects monitoring timing, geographic locations, research themes, responsible parties, before the oil reaches a shoreline. Unified command, responsible party, and legislated requirements.
- Mechanism for following a spill long-term until resolution of any long-term effects, especially on longer-lived organisms. *Valdez* with a great funding reserve, and *DWH* that went for a while, but not enough.
- Realization that many of these recommendations are not feasible, especially when dealing with on-the-ground oil spill cleanup, containment of oil, and mitigation efforts. But…

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From the Committee and Staff of Oil in the Sea IV,

Thank you!

Questions or Comments?
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