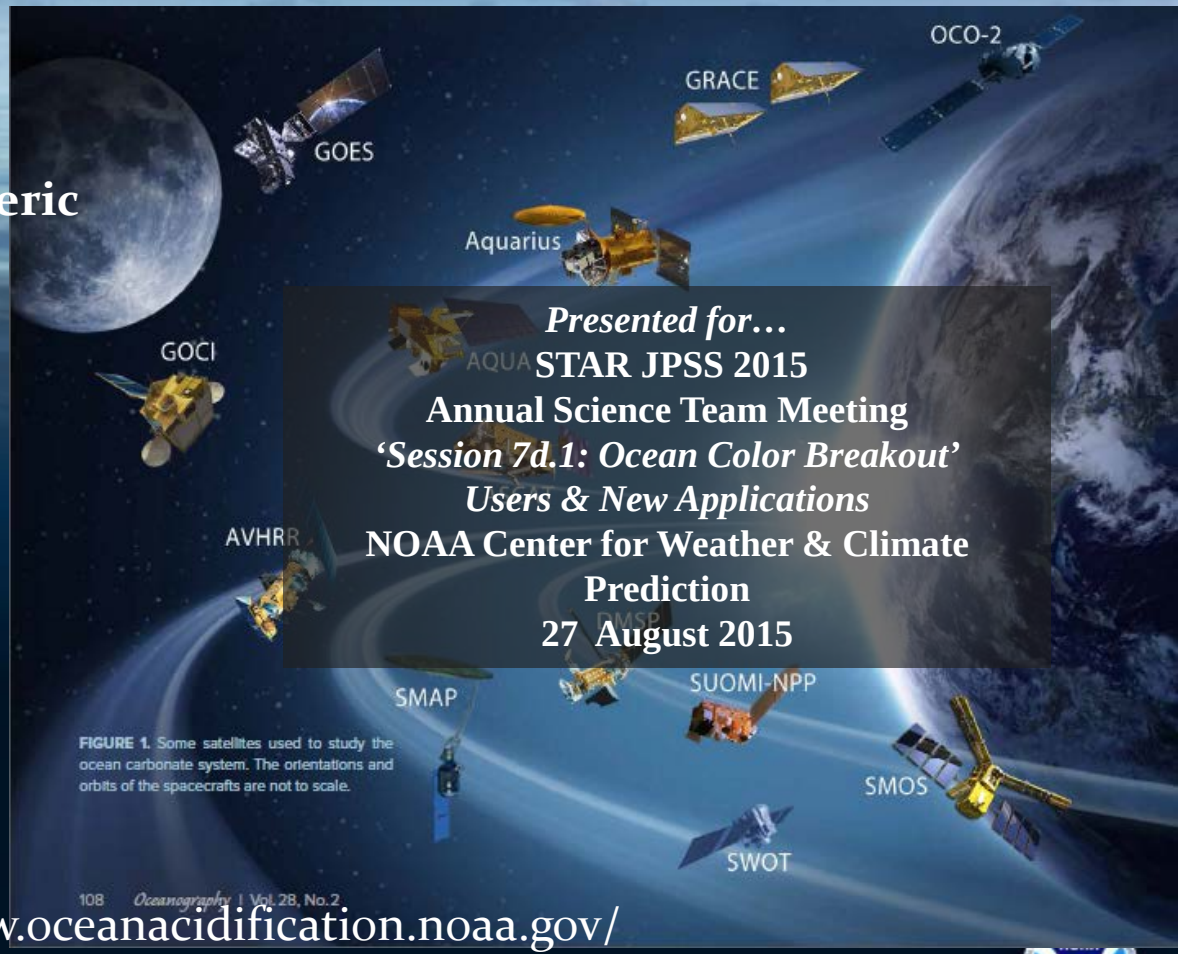
HOW SATELLITE OCEAN COLOR CAN AID OUR UNDERSTANDING OF OCEAN ACIDIFICATION

National Oceanic & Atmospheric Association (NOAA)

Ocean Acidification Program Office

Dwight Gledhill, NOAA OAP
Deputy Director

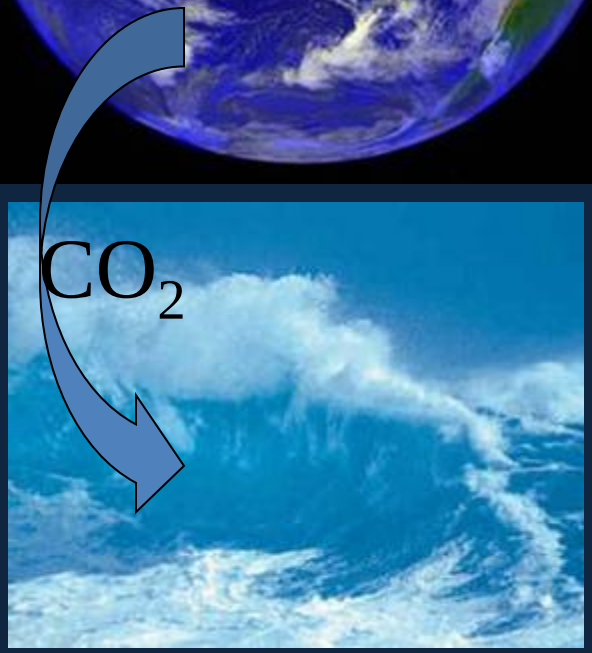


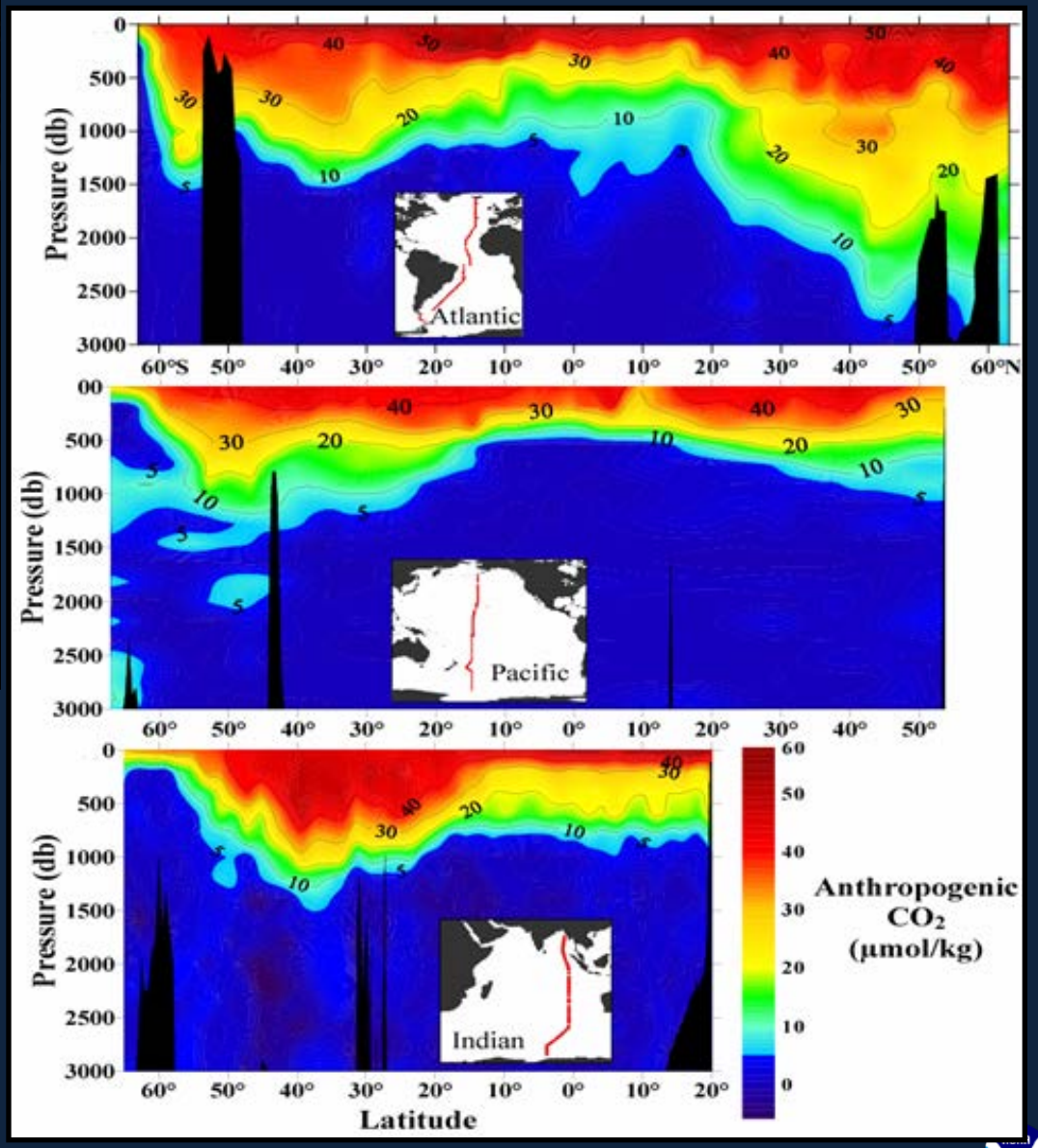
Presented for…
STAR JPSS 2015
Annual Science Team Meeting
'Session 7d.1: Ocean Color Breakout'
Users & New Applications
NOAA Center for Weather & Climate Prediction
27 August 2015

http://www.oceanacidification.noaa.gov/

NOAA OCEAN ACIDIFICATION PROGRAM

Ocean Acidification



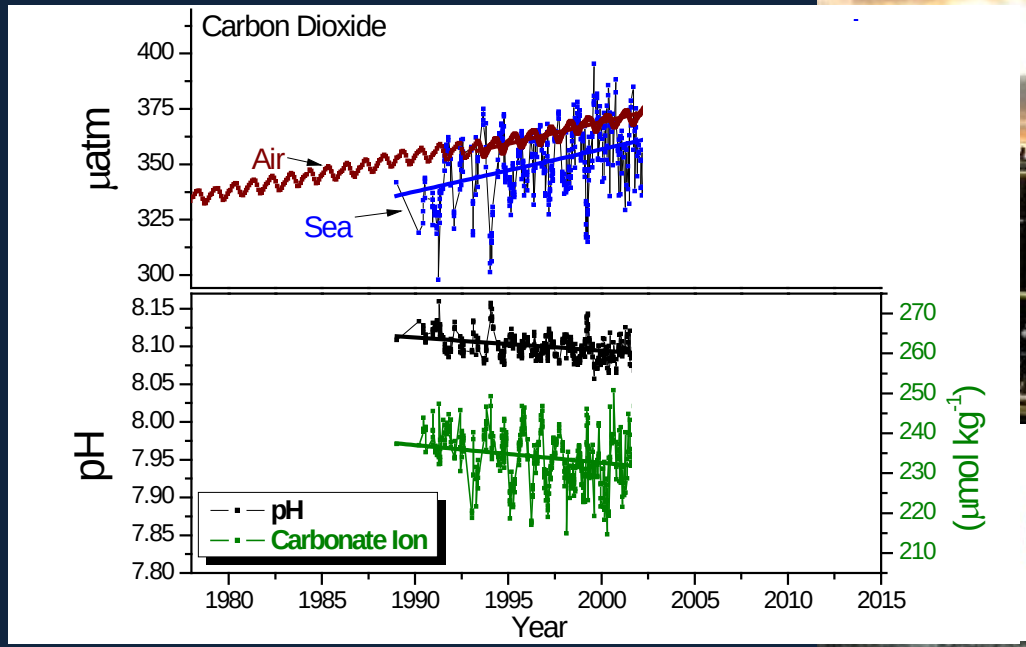


Sabine et al. Science (2004)

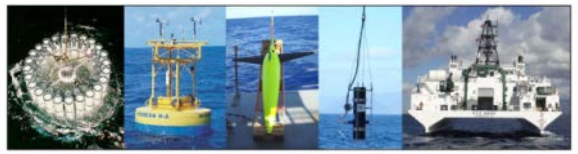
Ocean Acidification

$$CO_{2,gas} + H_2O \rightarrow H^+ + HCO_3^-$$

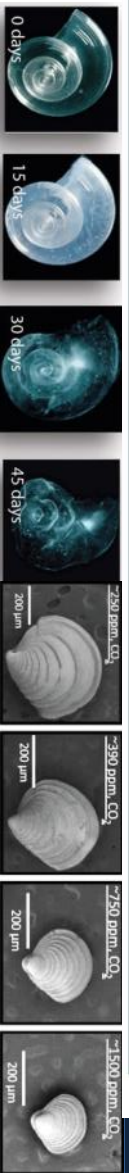
$$H^+ + CO_3^{2-} \rightarrow HCO_3^-$$



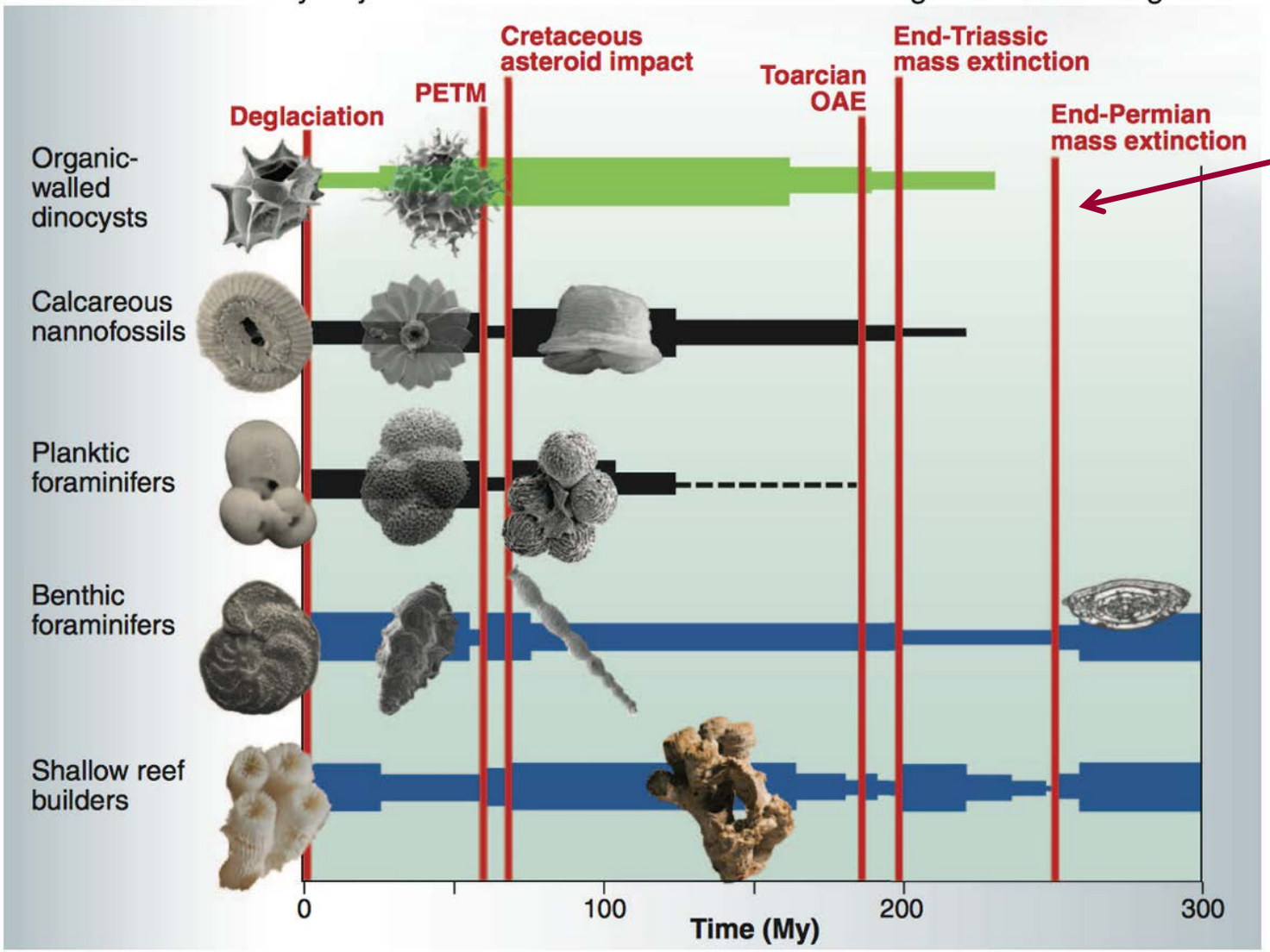
Hawaii Ocean Time-series (HOT)



How significant are these changes?



Idealized diversity trajectories of selected calcareous and organic fossil lineages.



Source: Honisch et al 2012

2.4 PgC/year

Clarkson et al., 2015

Current fossil fuel emission rates
8.3 PgC/year

Federal Ocean Acidification Research and Monitoring (FOARAM) Act of 2009

The **NOAA Ocean Acidification Program** (OAP) was established under SEC. 12406. of the Federal Ocean Acidification and Monitoring Act (FOARAM) to oversee and coordinate research, monitoring, and other activities consistent with the strategic research and implementation plan developed by the interagency working group on ocean acidification.

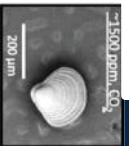
The program is to foster and direct …the establishment of a **long-term monitoring program of ocean acidification** utilizing existing global and national ocean observing assets, and adding instrumentation and sampling stations as appropriate to the aims of the research program…

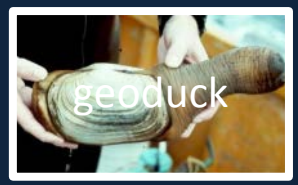
agency Working
ip on Ocean Acidification

oceanacidification.noaa.gov/IWGOA.aspx

Species Response to Ocean Acidification

NOAA OCEAN ACIDIFICATION PROGRAM





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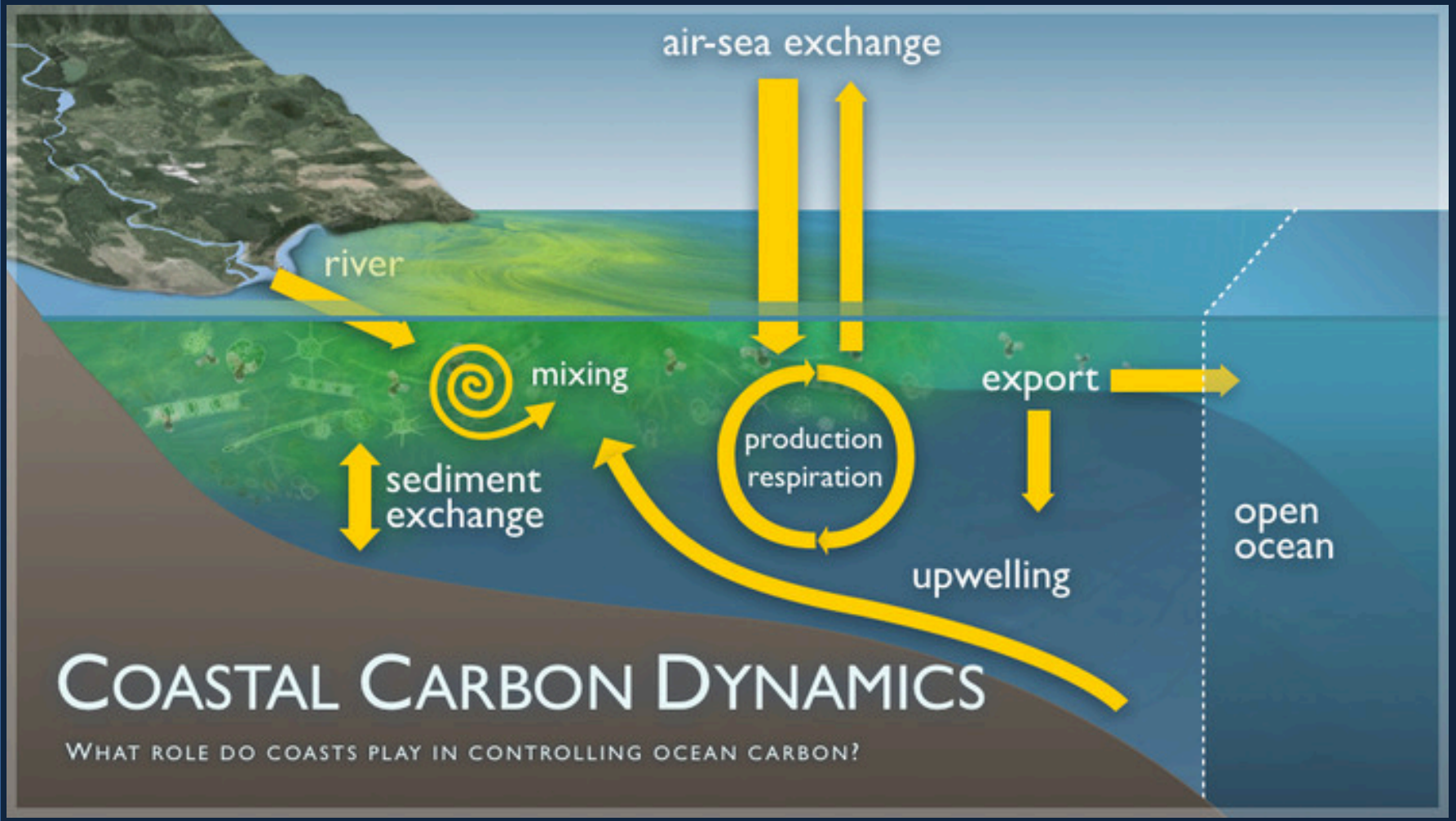
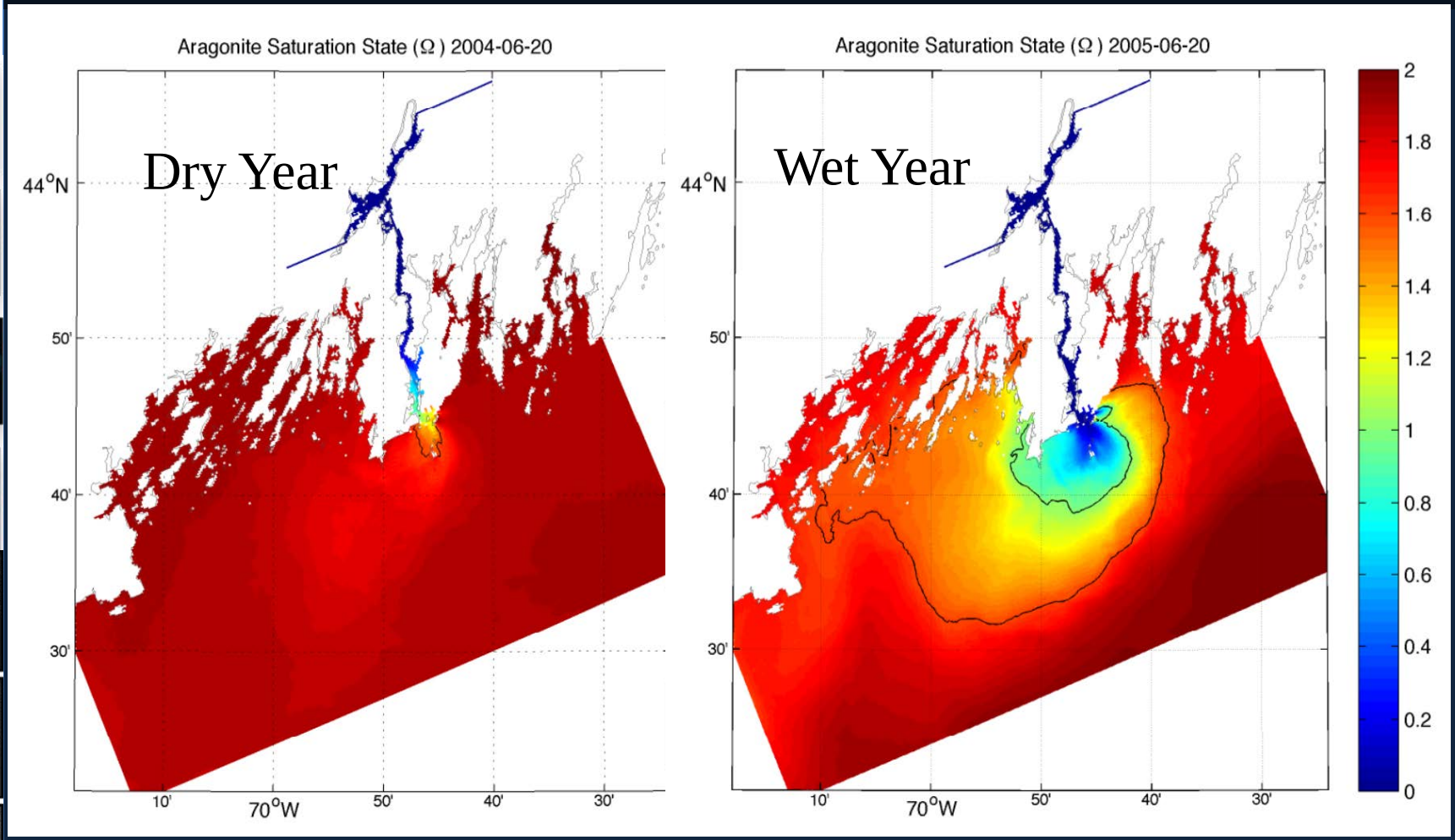
ONGOING ?

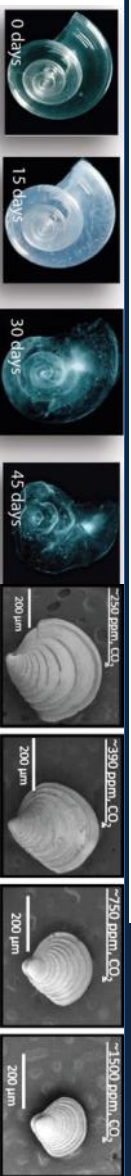
Ocean Acidification v2.0

v2.0 v1.0



Ocean Acidification v2.0

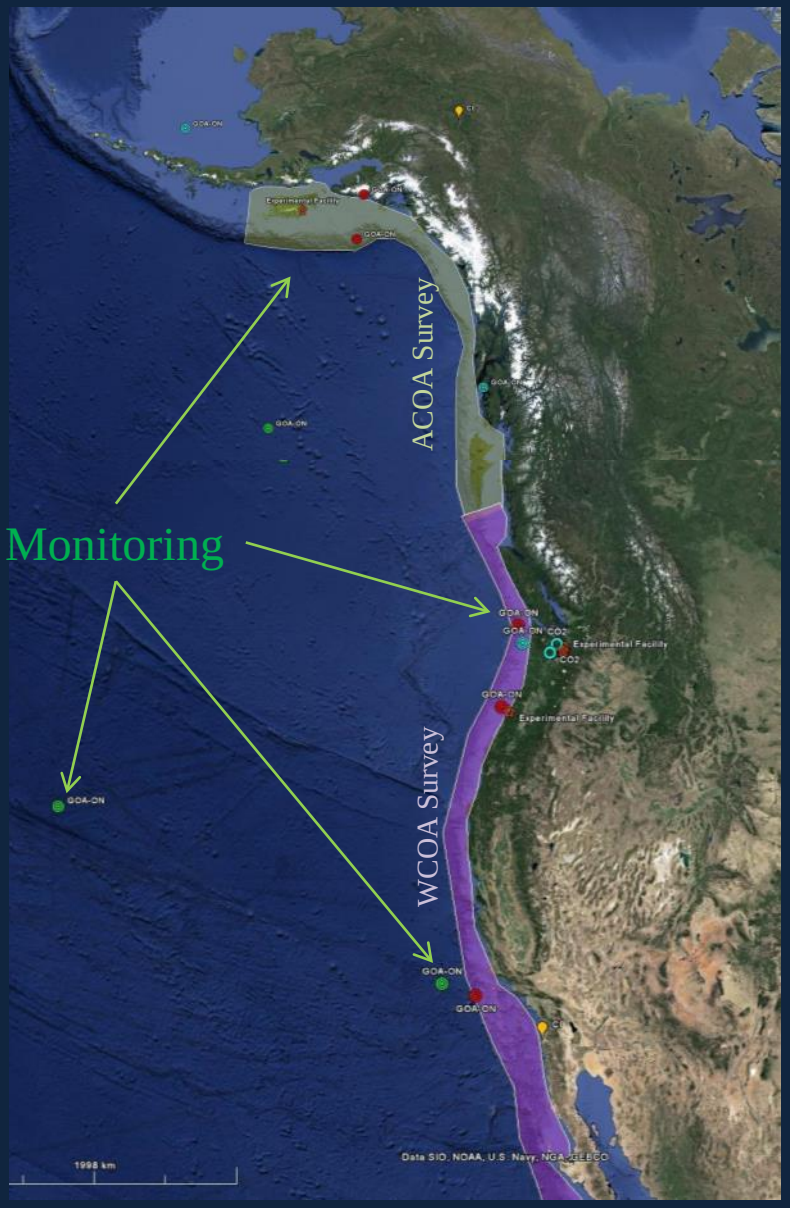




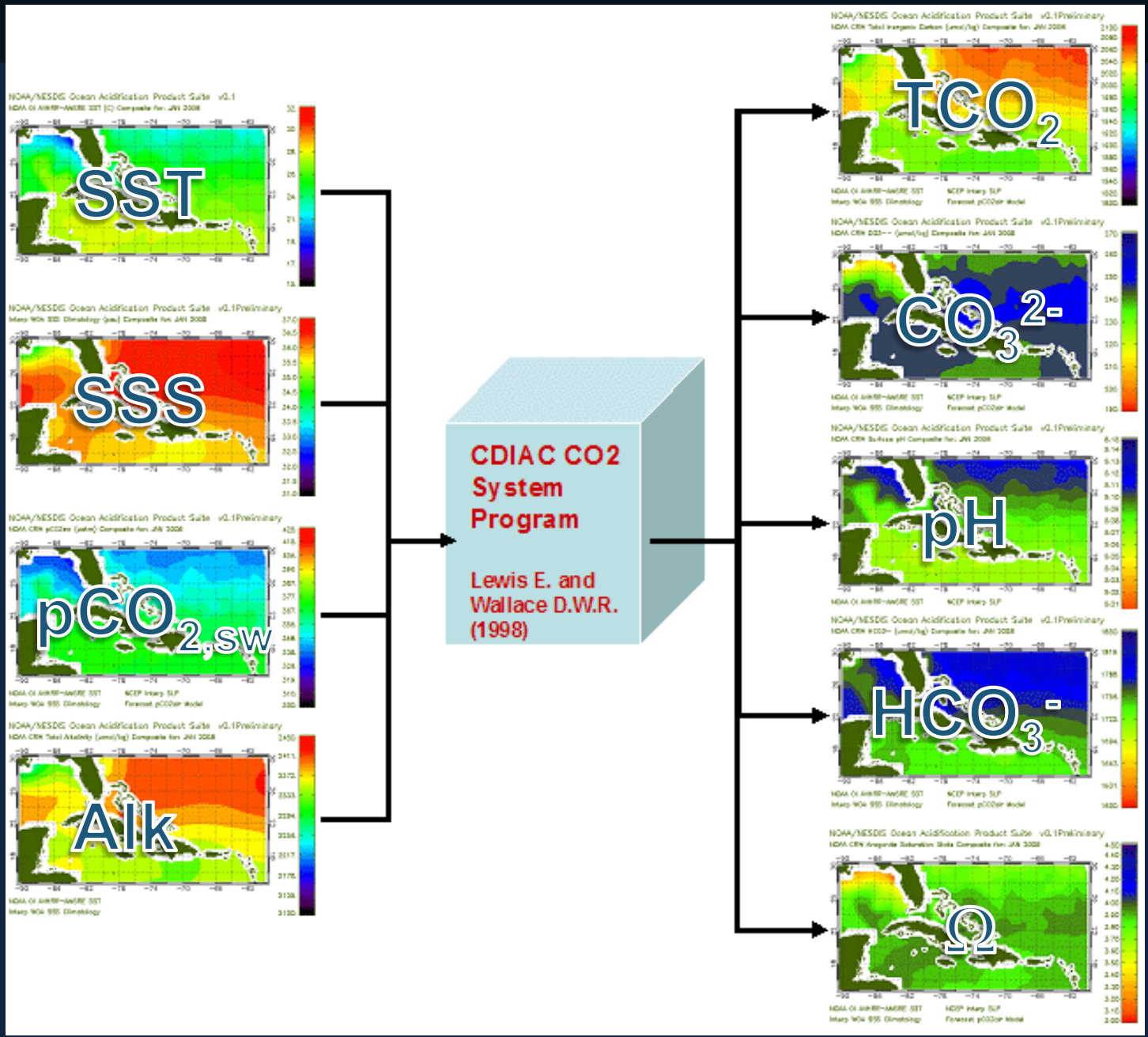
Corrosive plume off Casco Bay, Maine:

Salisbury et al., UHN

NOAA Ocean Acidification Monitoring



Remotely Sensing Ocean Acidification



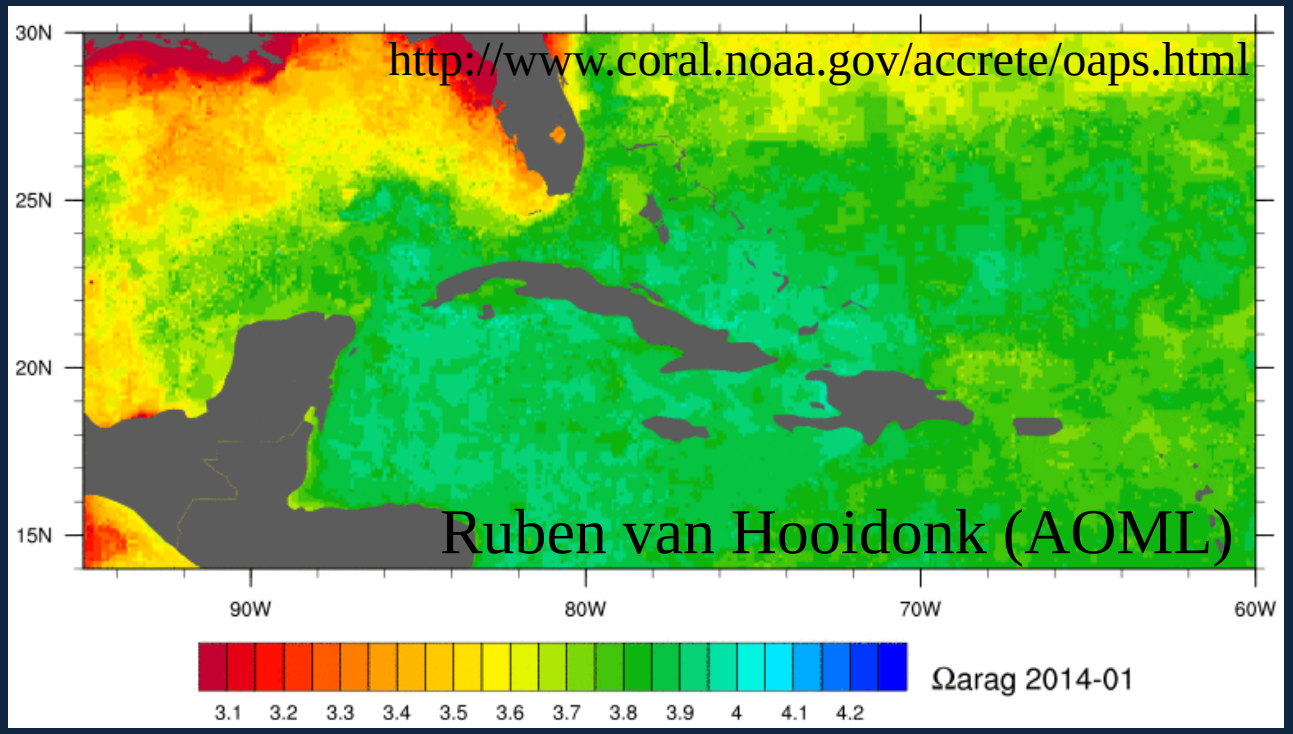
Remotely Sensing Ocean Acidification

$$A_T = a + b(SSS - 35) + c(SSS - 35)^2 + d(SST - 20) + e(SST - 20)^2$$

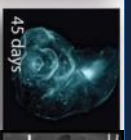
Lee, K., L. T. Tong, et al. (2006). "Global relationships of total alkalinity with salinity and temperature in surface waters of the world's oceans." Geophysical Research Letters **33**.

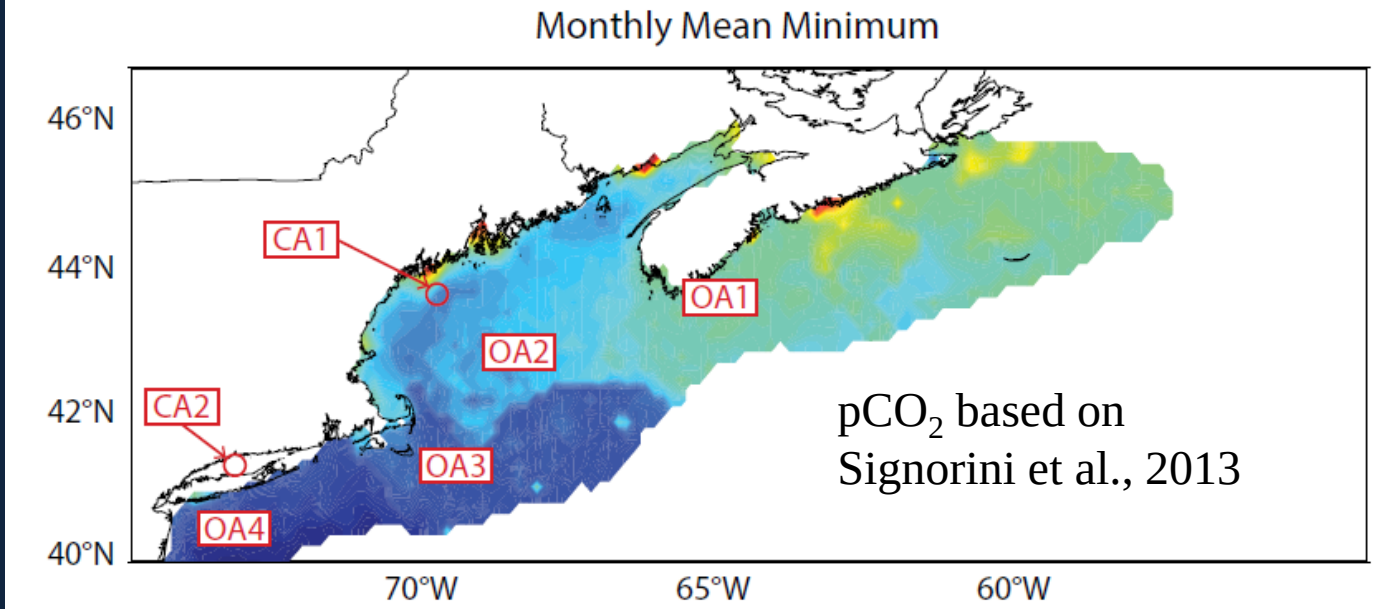
$$pCO_{2,sw} = y_0 + A\, e^{(-K_0/B)} + pCO_{2,air}$$

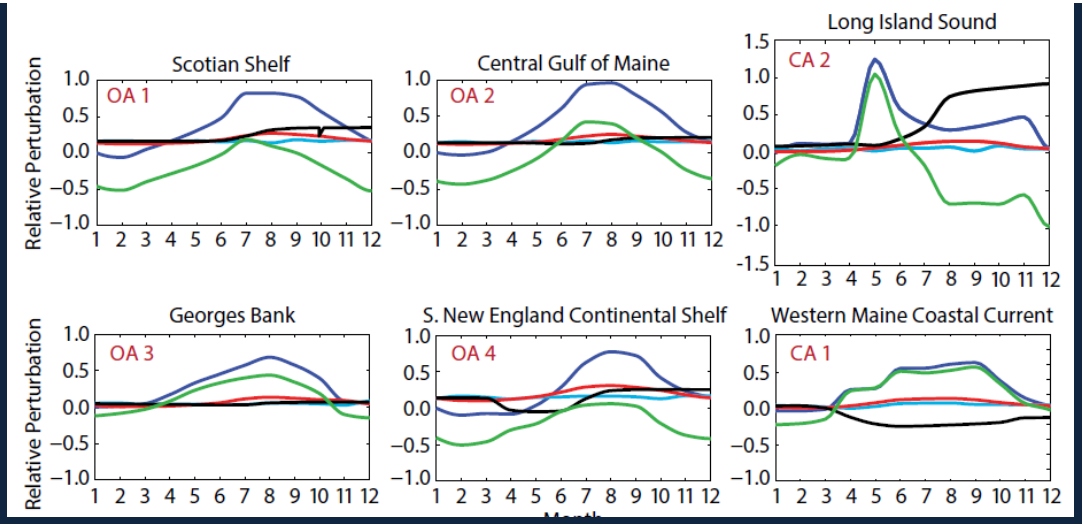
Gledhill, D, R. Wanninkhof, et al. (2008). "Ocean Acidification of the Greater Caribbean 1996-2008." JGR **113**.



Remotely Sensing Ocean Acidification



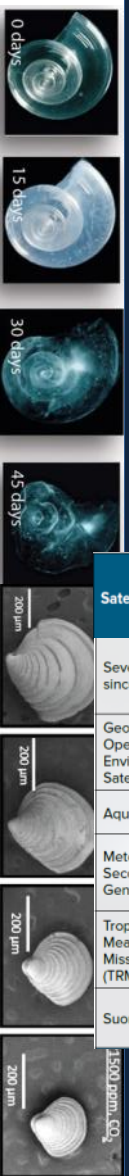


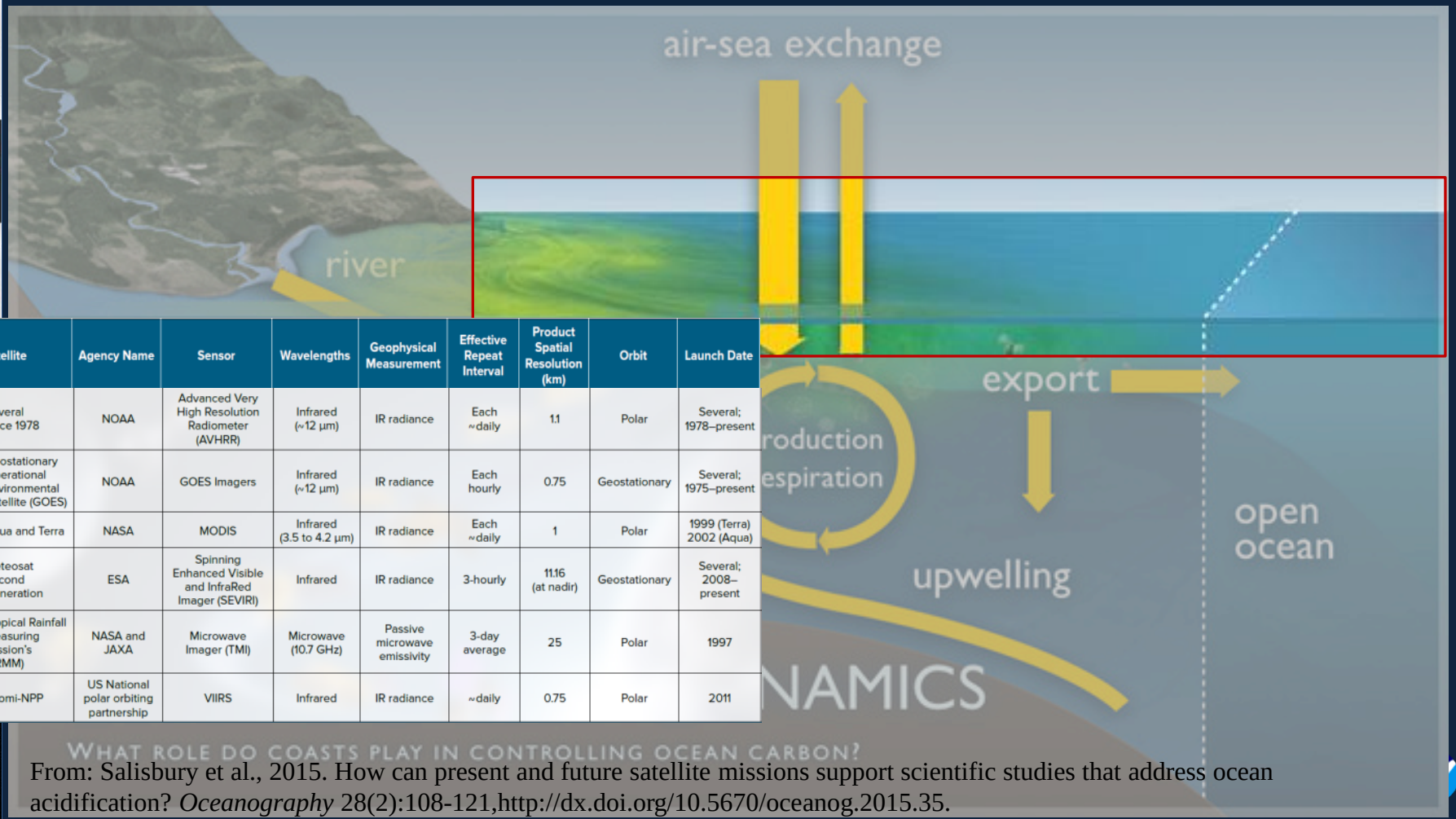


Gledhill et al., 2015. Ocean and Coastal Acidification off New England and Nova Scotia. *Oceanography* 28(2):182-197,http://dx.doi.org/10.5670/oceanog.2015.41.

Sea Surface Temperature Application to OA

Application: temperature, solubility of carbon dioxide, mineral solubility



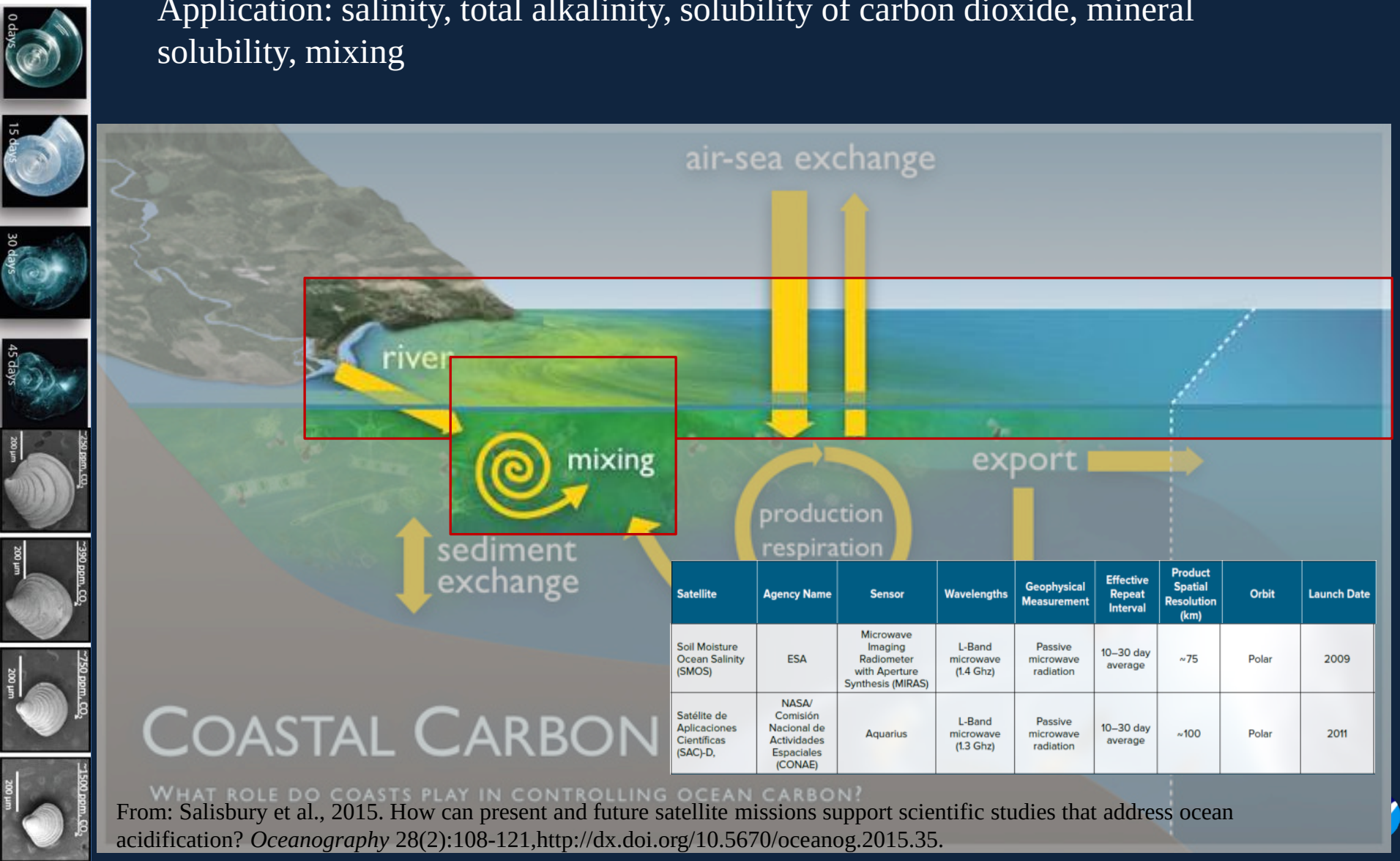


Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
Several since 1978	NOAA	Advanced Very High Resolution Radiometer (AVHRR)	Infrared (~12 µm)	IR radiance	Each ~daily	1.1	Polar	Several; 1978–present
Geostationary Operational Environmental Satellite (GOES)	NOAA	GOES Imagers	Infrared (~12 µm)	IR radiance	Each hourly	0.75	Geostationary	Several; 1975–present
Aqua and Terra	NASA	MODIS	Infrared (3.5 to 4.2 µm)	IR radiance	Each ~daily	1	Polar	1999 (Terra) 2002 (Aqua)
Meteosat Second Generation	ESA	Spinning Enhanced Visible and InfraRed Imager (SEVIRI)	Infrared	IR radiance	3-hourly	11.16 (at nadir)	Geostationary	Several; 2008–present
Tropical Rainfall Measuring Mission's (TRMM)	NASA and JAXA	Microwave Imager (TMI)	Microwave (10.7 GHz)	Passive microwave emissivity	3-day average	25	Polar	1997
Suomi-NPP	US National polar orbiting partnership	VIIRS	Infrared	IR radiance	~daily	0.75	Polar	2011

From: Salisbury et al., 2015. How can present and future satellite missions support scientific studies that address ocean acidification? *Oceanography* 28(2):108-121,http://dx.doi.org/10.5670/oceanog.2015.35.

Salinity Sensors Application to OA

Application: salinity, total alkalinity, solubility of carbon dioxide, mineral solubility, mixing

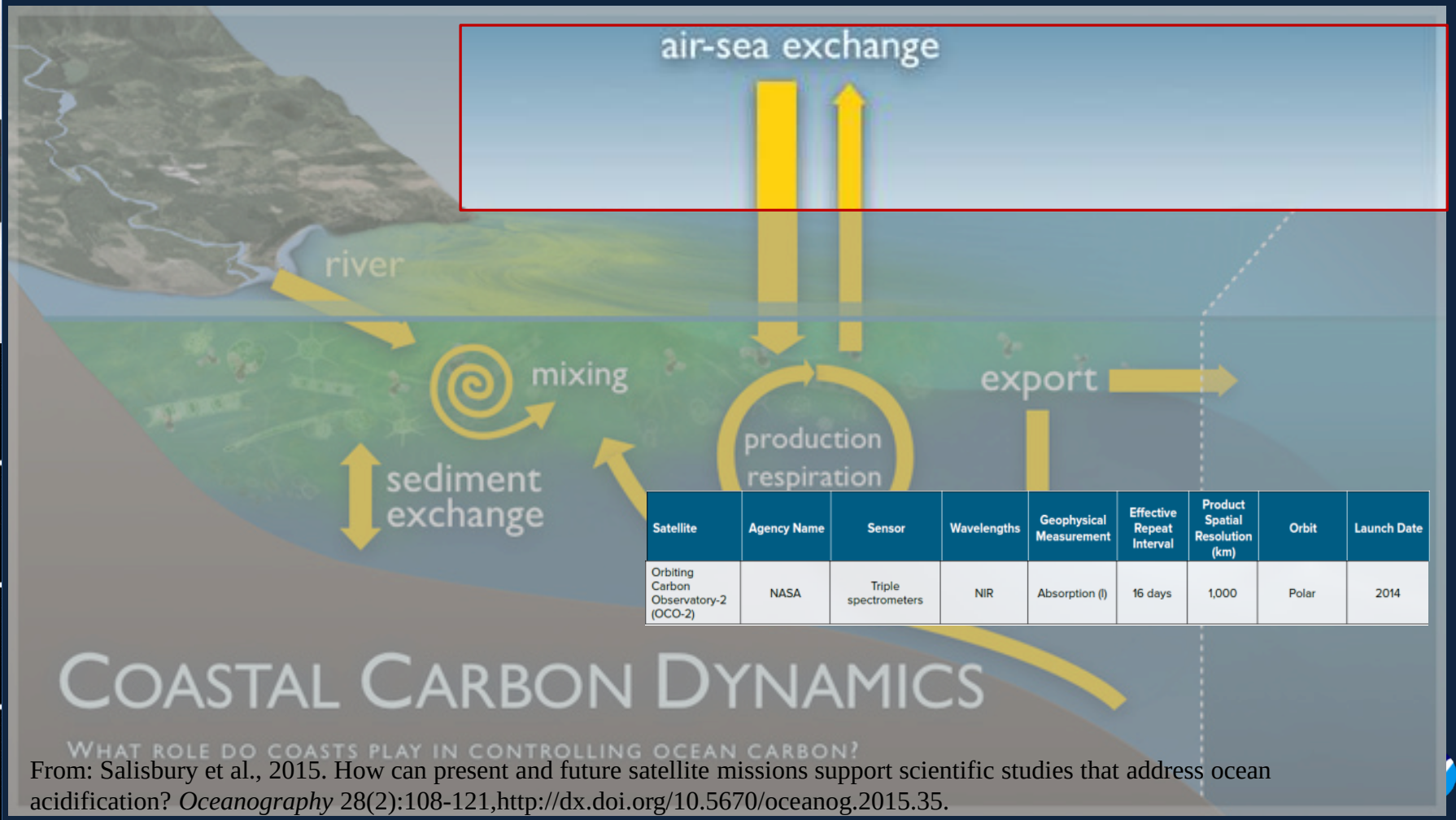


Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
Soil Moisture Ocean Salinity (SMOS)	ESA	Microwave Imaging Radiometer with Aperture Synthesis (MIRAS)	L-Band microwave (1.4 Ghz)	Passive microwave radiation	10–30 day average	~75	Polar	2009
Satélite de Aplicaciones Científicas (SAC)-D,	NASA/ Comisión Nacional de Actividades Espaciales (CONAE)	Aquarius	L-Band microwave (1.3 Ghz)	Passive microwave radiation	10–30 day average	~100	Polar	2011

From: Salisbury et al., 2015. How can present and future satellite missions support scientific studies that address ocean acidification? *Oceanography* 28(2):108-121,http://dx.doi.org/10.5670/oceanog.2015.35.

Atmospheric CO_2 Application to OA

Application: air-sea gas disequilibrium, secular changes in OA



Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
Orbiting Carbon Observatory-2 (OCO-2)	NASA	Triple spectrometers	NIR	Absorption (I)	16 days	1,000	Polar	2014

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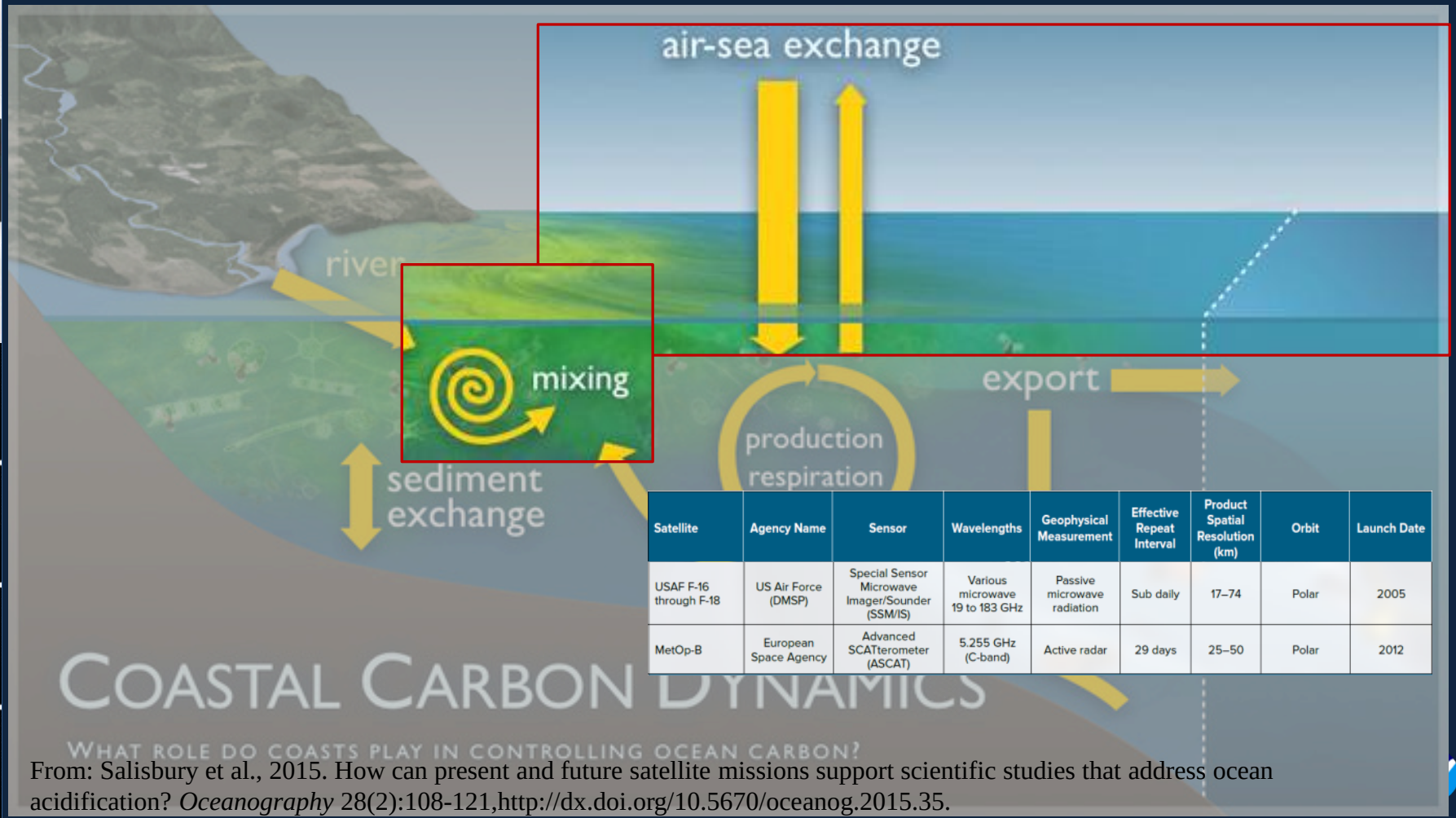
Scatterometrers/Radiometers Application to OA

Application: air-sea gas exchange



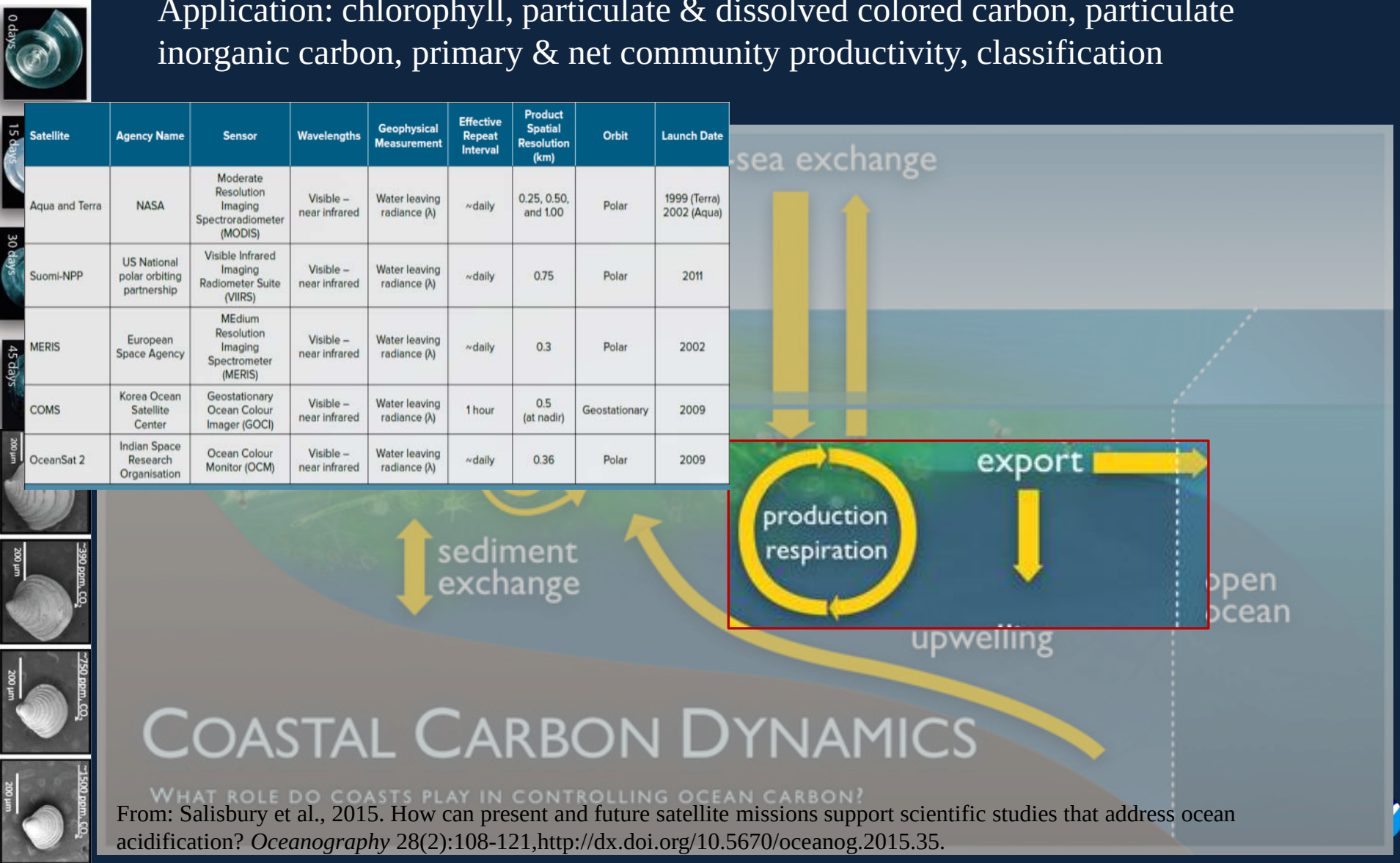
Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
USAF F-16 through F-18	US Air Force (DMSP)	Special Sensor Microwave Imager/Sounder (SSM/IS)	Various microwave 19 to 183 GHz	Passive microwave radiation	Sub daily	17–74	Polar	2005
MetOp-B	European Space Agency	Advanced SCATterometer (ASCAT)	5.255 GHz (C-band)	Active radar	29 days	25–50	Polar	2012

From: Salisbury et al., 2015. How can present and future satellite missions support scientific studies that address ocean acidification? *Oceanography* 28(2):108-121,http://dx.doi.org/10.5670/oceanog.2015.35.

Satellite Ocean Color Application to OA

Application: chlorophyll, particulate & dissolved colored carbon, particulate inorganic carbon, primary & net community productivity, classification

Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
Aqua and Terra	NASA	Moderate Resolution Imaging Spectroradiometer (MODIS)	Visible – near infrared	Water leaving radiance (λ)	~daily	0.25, 0.50, and 1.00	Polar	1999 (Terra) 2002 (Aqua)
Suomi-NPP	US National polar orbiting partnership	Visible Infrared Imaging Radiometer Suite (VIIRS)	Visible – near infrared	Water leaving radiance (λ)	~daily	0.75	Polar	2011
MERIS	European Space Agency	MEdium Resolution Imaging Spectrometer (MERIS)	Visible – near infrared	Water leaving radiance (λ)	~daily	0.3	Polar	2002
COMS	Korea Ocean Satellite Center	Geostationary Ocean Colour Imager (GOCI)	Visible – near infrared	Water leaving radiance (λ)	1 hour	0.5 (at nadir)	Geostationary	2009
OceanSat 2	Indian Space Research Organisation	Ocean Colour Monitor (OCM)	Visible – near infrared	Water leaving radiance (λ)	~daily	0.36	Polar	2009

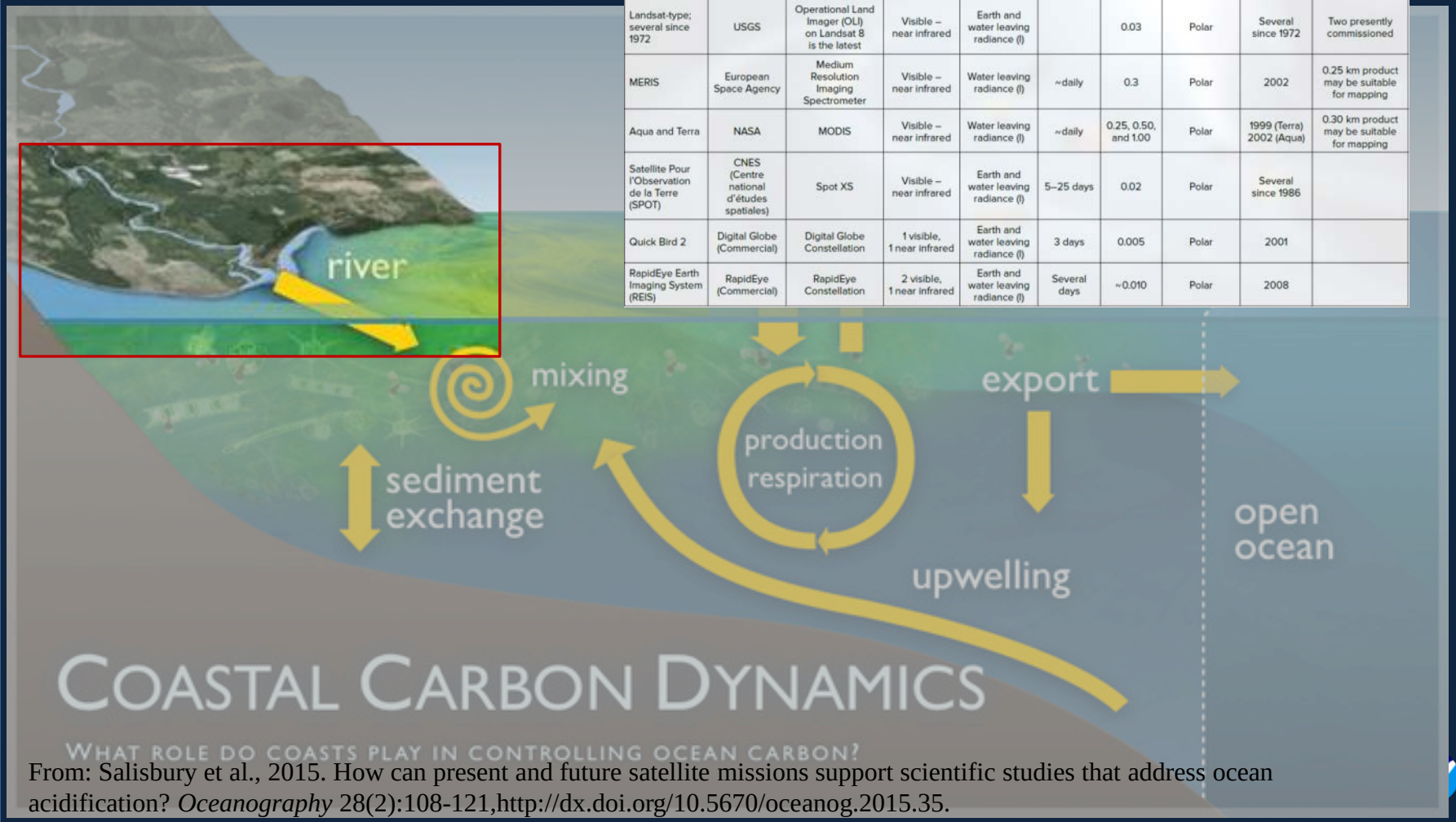


From: Salisbury et al., 2015. How can present and future satellite missions support scientific studies that address ocean acidification? *Oceanography* 28(2):108-121,http://dx.doi.org/10.5670/oceanog.2015.35.

Coastal Mapping Application to OA

Application: coral reef area, coral reef health, shallow water resuspension, near coastal processes

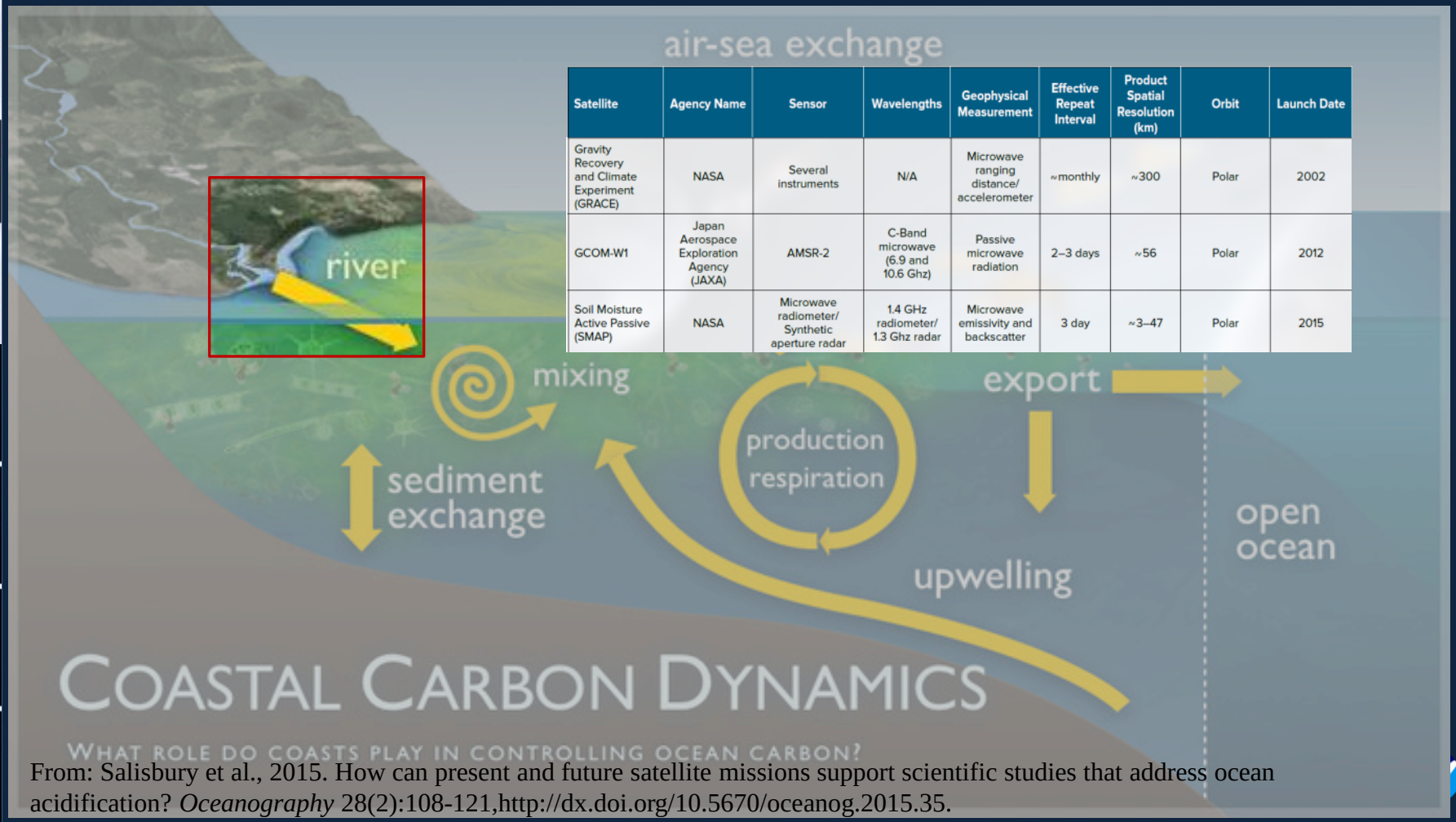
Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
Landsat-type; several since 1972	USGS	Operational Land Imager (OLI) on Landsat 8 is the latest	Visible – near infrared	Earth and water leaving radiance (l)	0.03	Polar	Several since 1972	Two presently commissioned
MERIS	European Space Agency	Medium Resolution Imaging Spectrometer	Visible – near infrared	Water leaving radiance (l)	~daily	0.3	Polar	2002	0.25 km product may be suitable for mapping
Aqua and Terra	NASA	MODIS	Visible – near infrared	Water leaving radiance (l)	~daily	0.25, 0.50, and 1.00	Polar	1999 (Terra) 2002 (Aqua)	0.30 km product may be suitable for mapping
Satellite Pour l'Observation de la Terre (SPOT)	CNES (Centre national d'études spatiales)	Spot XS	Visible – near infrared	Earth and water leaving radiance (l)	5–25 days	0.02	Polar	Several since 1986	
Quick Bird 2	Digital Globe (Commercial)	Digital Globe Constellation	1 visible, 1 near infrared	Earth and water leaving radiance (l)	3 days	0.005	Polar	2001	
RapidEye Earth Imaging System (REIS)	RapidEye (Commercial)	RapidEye Constellation	2 visible, 1 near infrared	Earth and water leaving radiance (l)	Several days	~0.010	Polar	2008	



From: Salisbury et al., 2015. How can present and future satellite missions support scientific studies that address ocean acidification? *Oceanography* 28(2):108-121,http://dx.doi.org/10.5670/oceanog.2015.35.

Soil Moisture/Water Budgets Application to OA

Application: water cycle studies, freshwater flux to the ocean

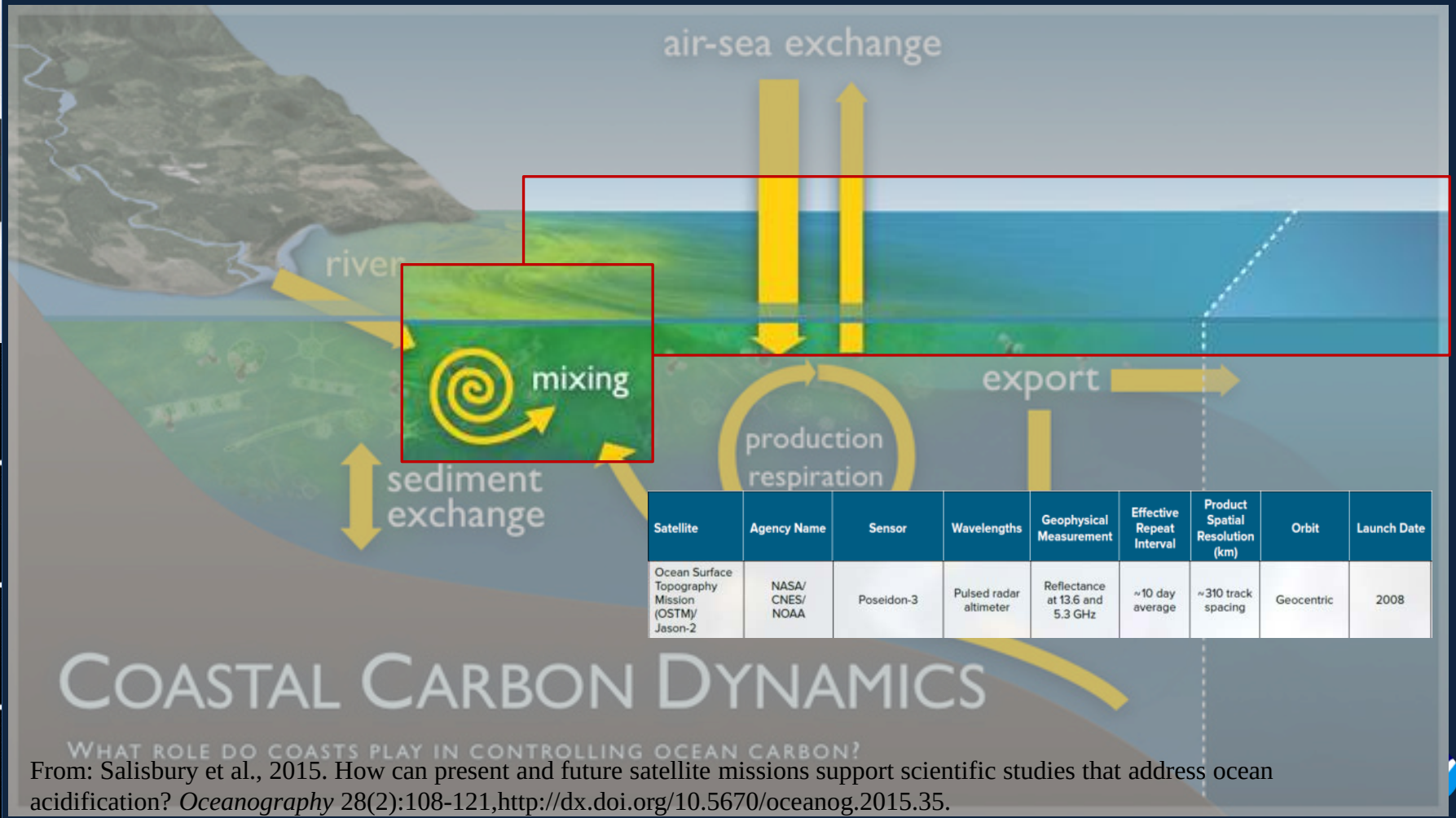


Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
Gravity Recovery and Climate Experiment (GRACE)	NASA	Several instruments	N/A	Microwave ranging distance/ accelerometer	~monthly	~300	Polar	2002
GCOM-W1	Japan Aerospace Exploration Agency (JAXA)	AMSR-2	C-Band microwave (6.9 and 10.6 Ghz)	Passive microwave radiation	2–3 days	~56	Polar	2012
Soil Moisture Active Passive (SMAP)	NASA	Microwave radiometer/ Synthetic aperture radar	1.4 GHz radiometer/ 1.3 Ghz radar	Microwave emissivity and backscatter	3 day	~3–47	Polar	2015

From: Salisbury et al., 2015. How can present and future satellite missions support scientific studies that address ocean acidification? *Oceanography* 28(2):108-121,http://dx.doi.org/10.5670/oceanog.2015.35.

Altimetry Application to OA

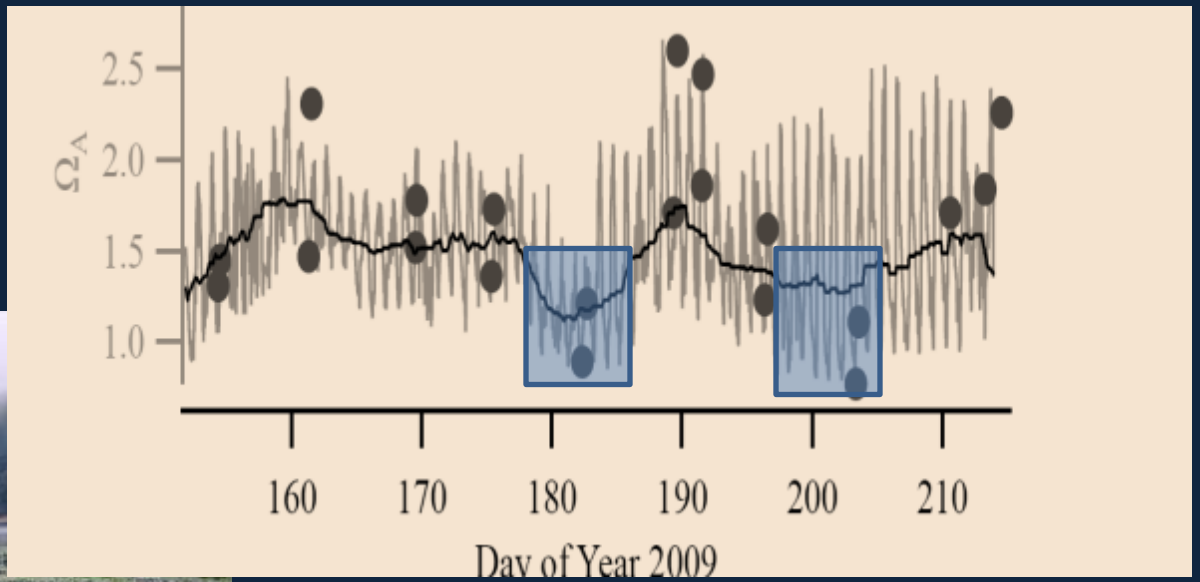
Application: ocean currents, mixing

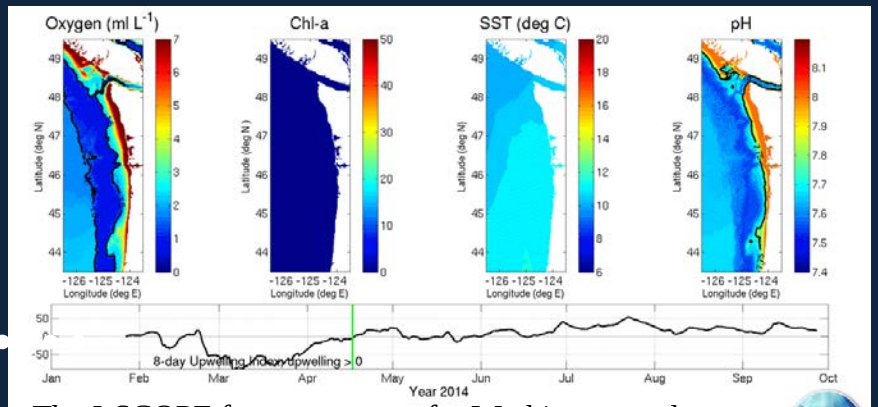


Satellite	Agency Name	Sensor	Wavelengths	Geophysical Measurement	Effective Repeat Interval	Product Spatial Resolution (km)	Orbit	Launch Date
Ocean Surface Topography Mission (OSTM)/ Jason-2	NASA/ CNES/ NOAA	Poseidon-3	Pulsed radar altimeter	Reflectance at 13.6 and 5.3 GHz	~10 day average	~310 track spacing	Geocentric	2008

From: Salisbury et al., 2015. How can present and future satellite missions support scientific studies that address ocean acidification? *Oceanography* 28(2):108-121,http://dx.doi.org/10.5670/oceanog.2015.35.

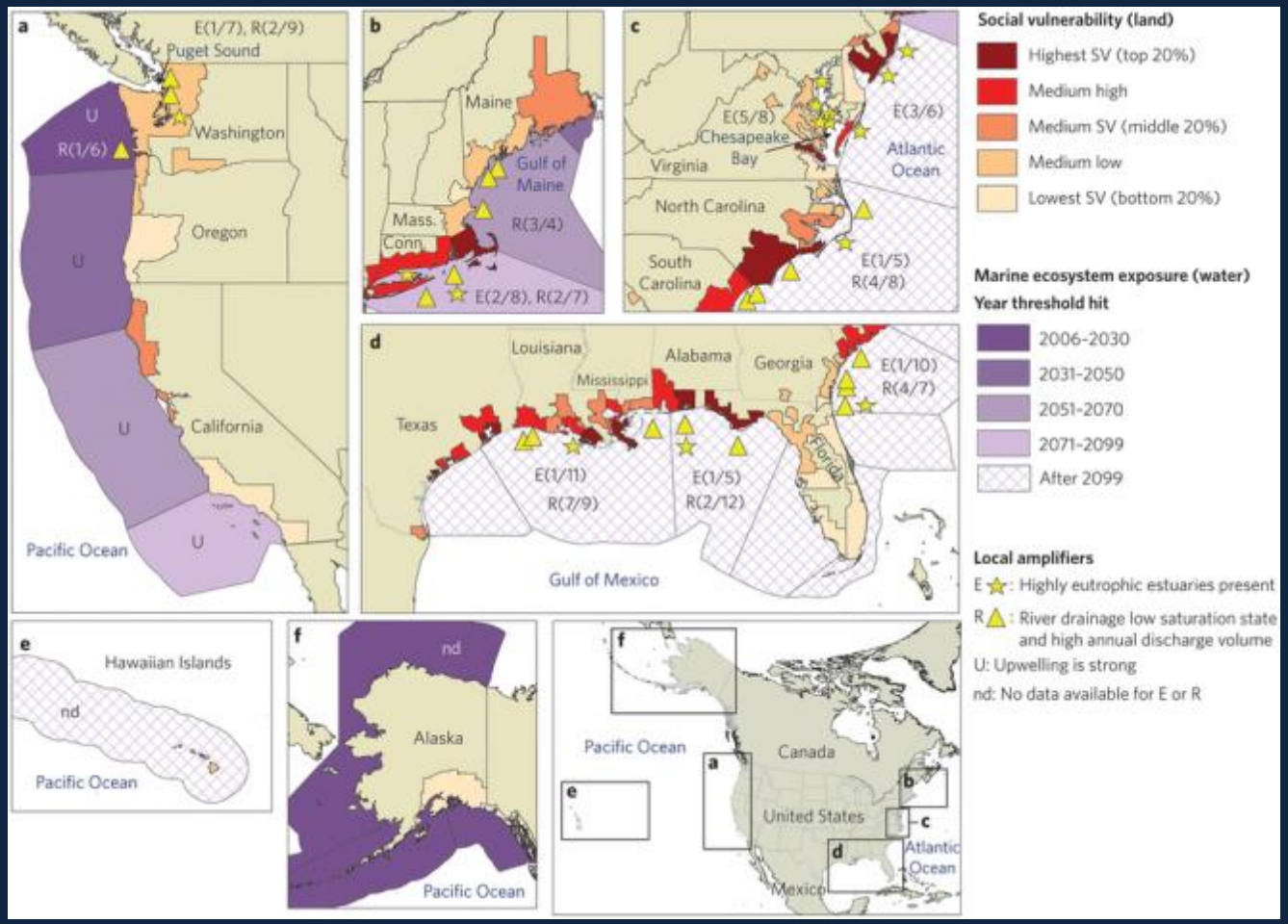
User Community and Stakeholders of OA Data





The J-SCOPE forecast system for Washington and Oregon coastal waters

User Community and Stakeholders of OA Data



Vulnerability and adaptation of US shellfisheries to ocean acidification. Ekstrom et al., Nature Climate Change 5, 207–214 (2015) doi:10.1038/nclimate2508

User Community and Stakeholders of OA Data

Applications, Tools, Products		
Name	Frequency	Users
LME 20xx Ecosystem Report Card	Annual	Alaska Fishery Management & Industries
Long-term bio-economic forecast	5-yr	Alaska Fishery Management & Industries
Regional Vulnerability Assessment	5-yr	Alaska Fishery Management & Industries
Regional OA Forecast & Scenario Projection	On-demand	New England and Mid-Atlantic Marine Fisheries Commission
Large Marine Ecosystem IEA	ND	Greater Atlantic Regional Fisheries Office
National Coral Reef Status & Trends Report Card	TBD	Regional Fishery Management Councils
Etc.		Coral Reef Management Community

Concluding Thoughts

- The vulnerability of society to the impacts of ocean acidification differs regionally due to local chemistry, biology, and economic dependence. This heterogeneity creates an opportunity for information product needs.
- Most of the user needs for OA data products emerge from the marine resource management and industry community in the form of synthesis assessments. Not necessarily nRT.
- Satellite Ocean Color products are particularly of aid in improving synoptic mapping of OA with the coastal domain where biological forcing imparts a first-order effect to carbonate system dynamics.
- Applications range from classification of water types for improved empirical relations to direct determination of relevant processes (e.g. NPP).
- Opportunities exist to further improve coastal/shelf algorithms by furthering joint OAR-NESDIS geochemical surveys (i.e. ECOA)

Thank you

http://oceanacidification.noaa.gov/