Transport of the Fukushima radioactivity plume to the Eastern North Pacific: impacts on biological resources

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2017 Annual PICES Meeting
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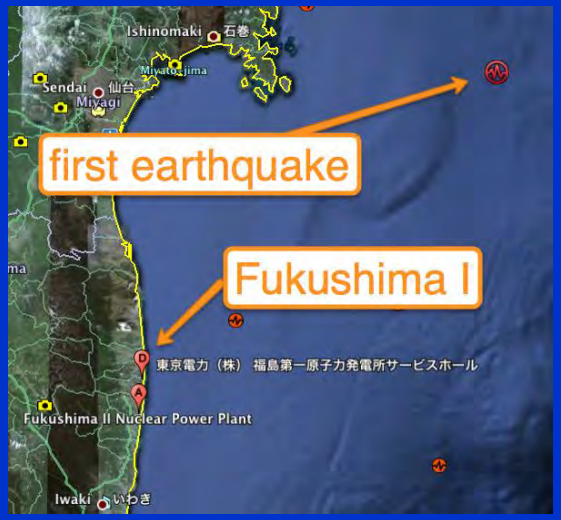
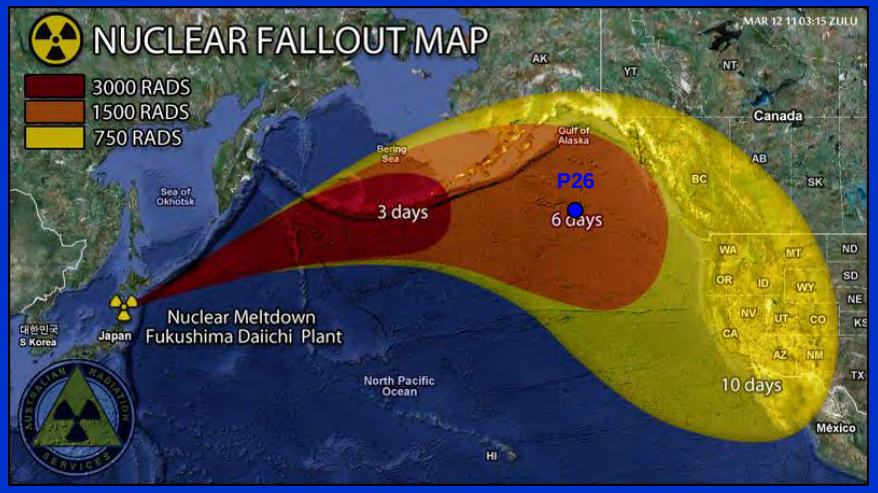
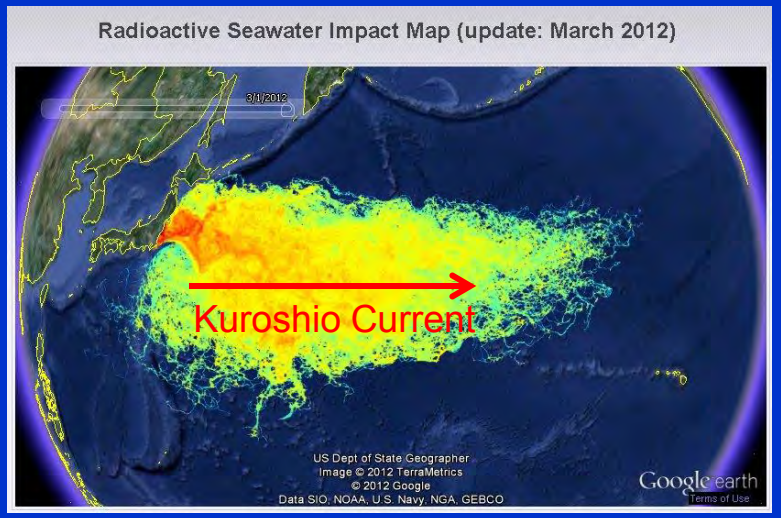


The March 11, 2011 earthquake-triggered tsunami resulted in damage to four of the six Fukushima nuclear power reactors.

Note: Accident resulted in no immediate deaths…some projected long term health impacts in evacuation zone.





Atmospheric transport of radioactivity plume was directed farther northeastward compared to more eastward transport of water borne plume driven by Kuroshio Current.

Devastating tsunami sweeps across northeastern Japan…

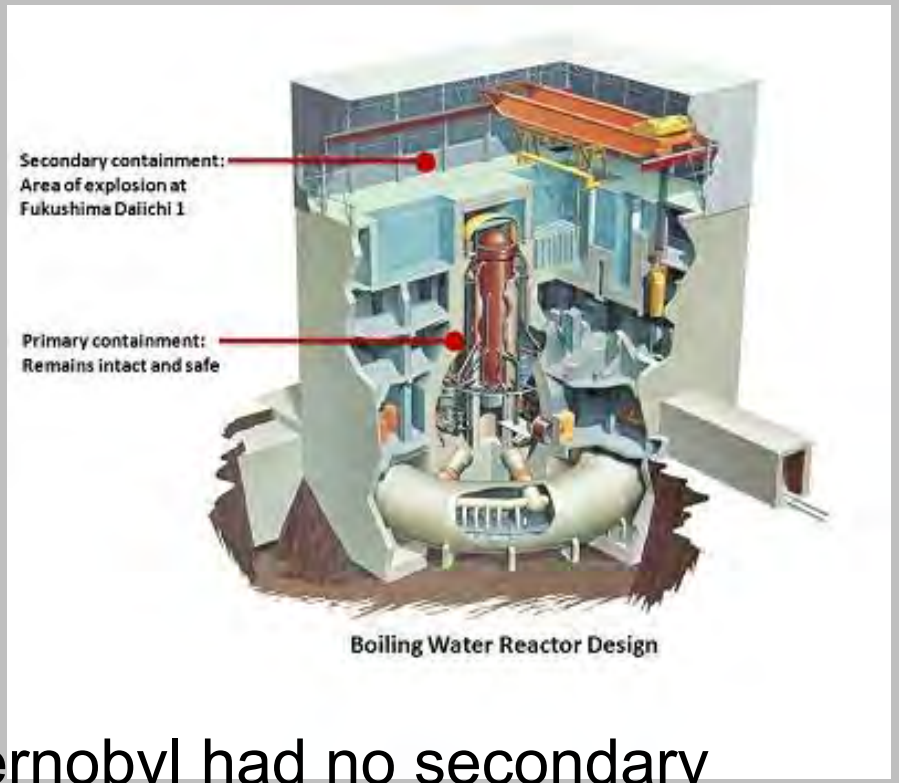
…approaches Fukushima Dai-ichi nuclear stations.

…tsunami swamps cooling pumps

Why did the explosions occur?

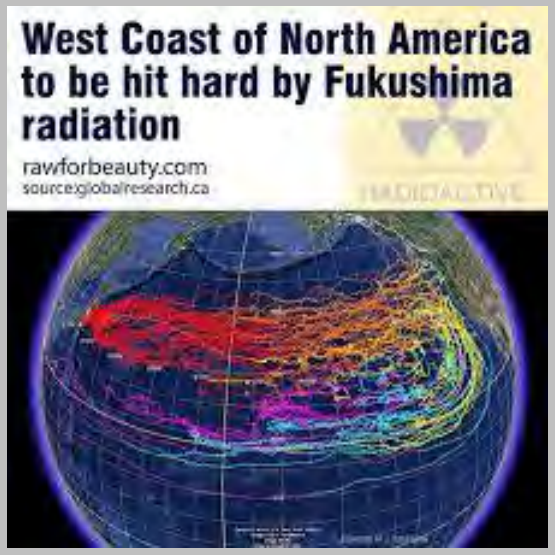
Zirconium (Zr) in fuel assemblies reacts with steam (H_2O) at high temperatures to produce hydrogen. H_2 was vented from nuclear core when cooling systems failed, but then reacted with O_2 explosively in outer containment buildings.

Cores did not explode.



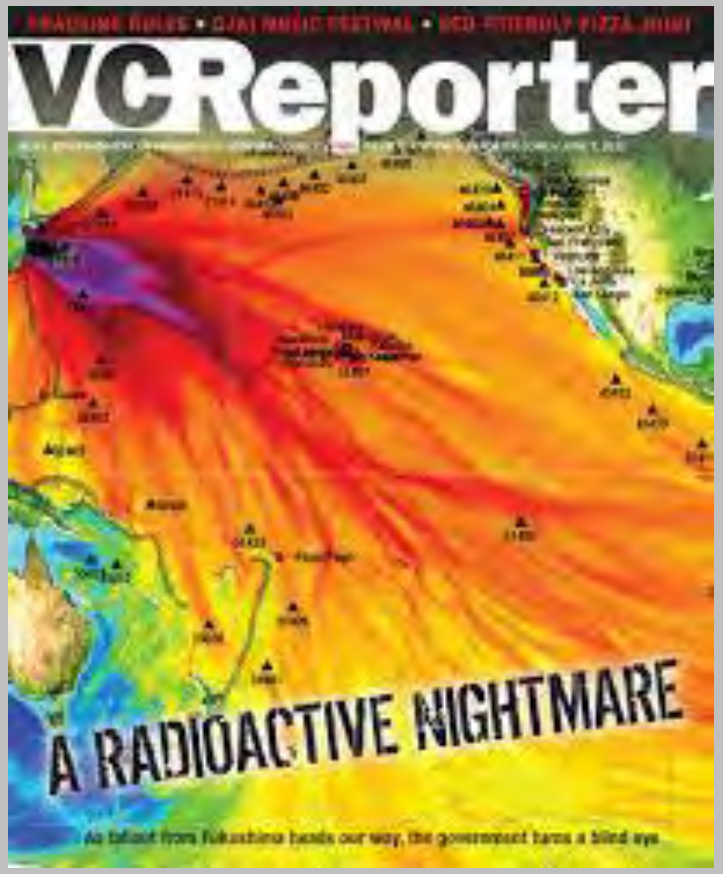
Chernobyl had no secondary containment!

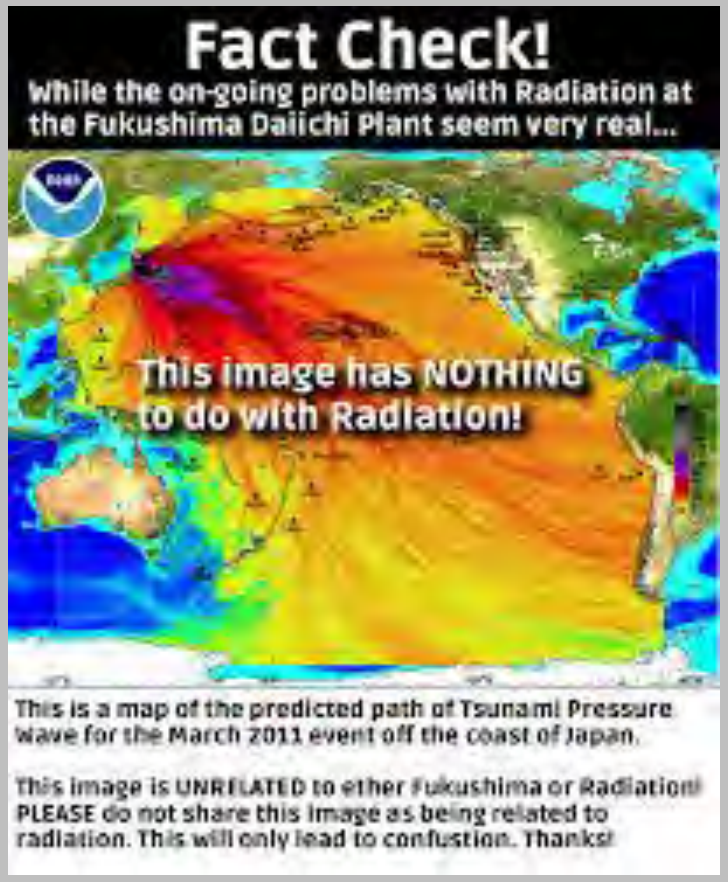
Why monitor Fukushima radioactivity?...



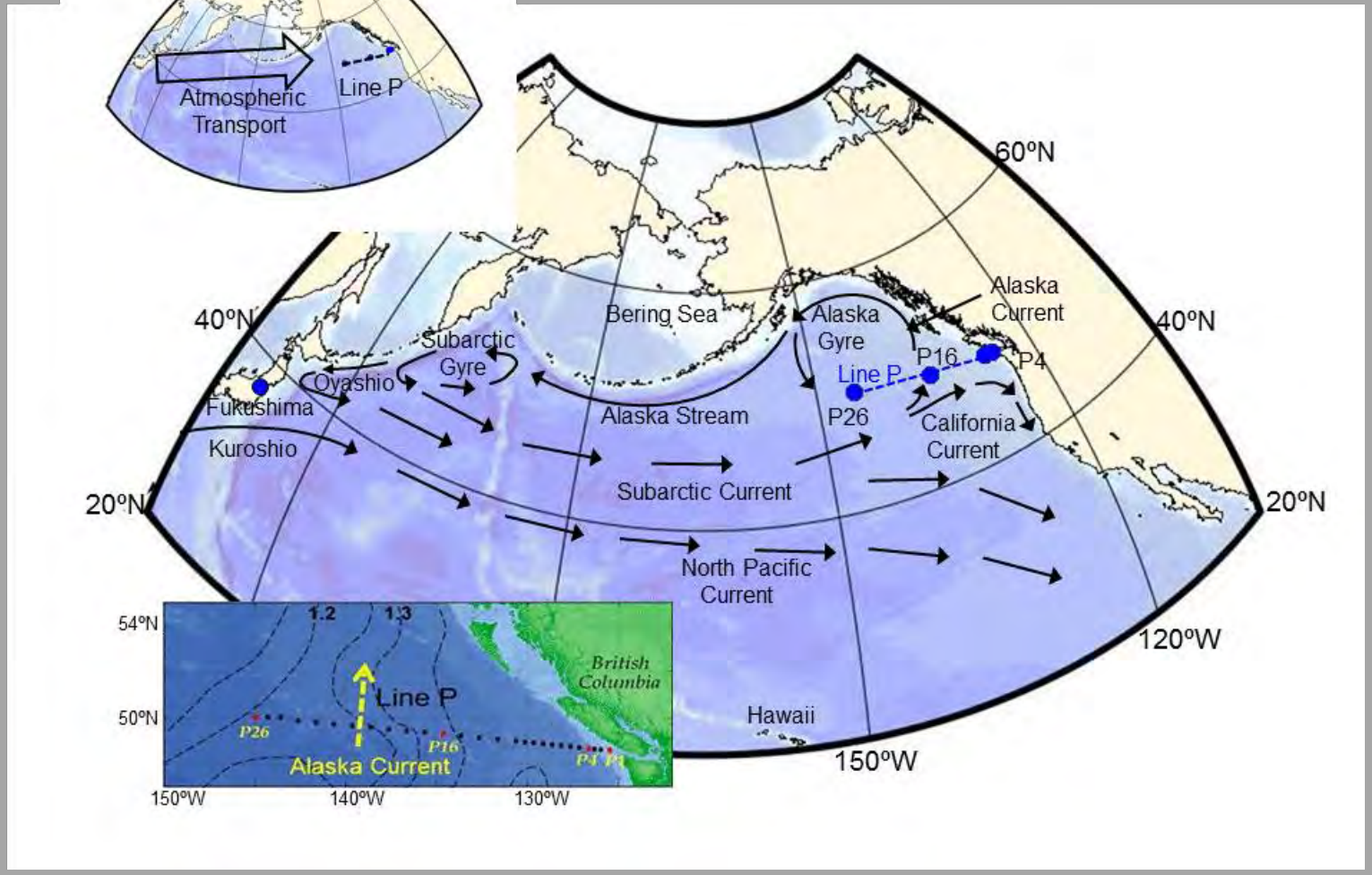
…to fill the information vacuum with real data!

Considerable public relations mischief: image below is related to tsunami wave heights transformed into “radioactive nightmare” requiring public disclaimer from NOAA.

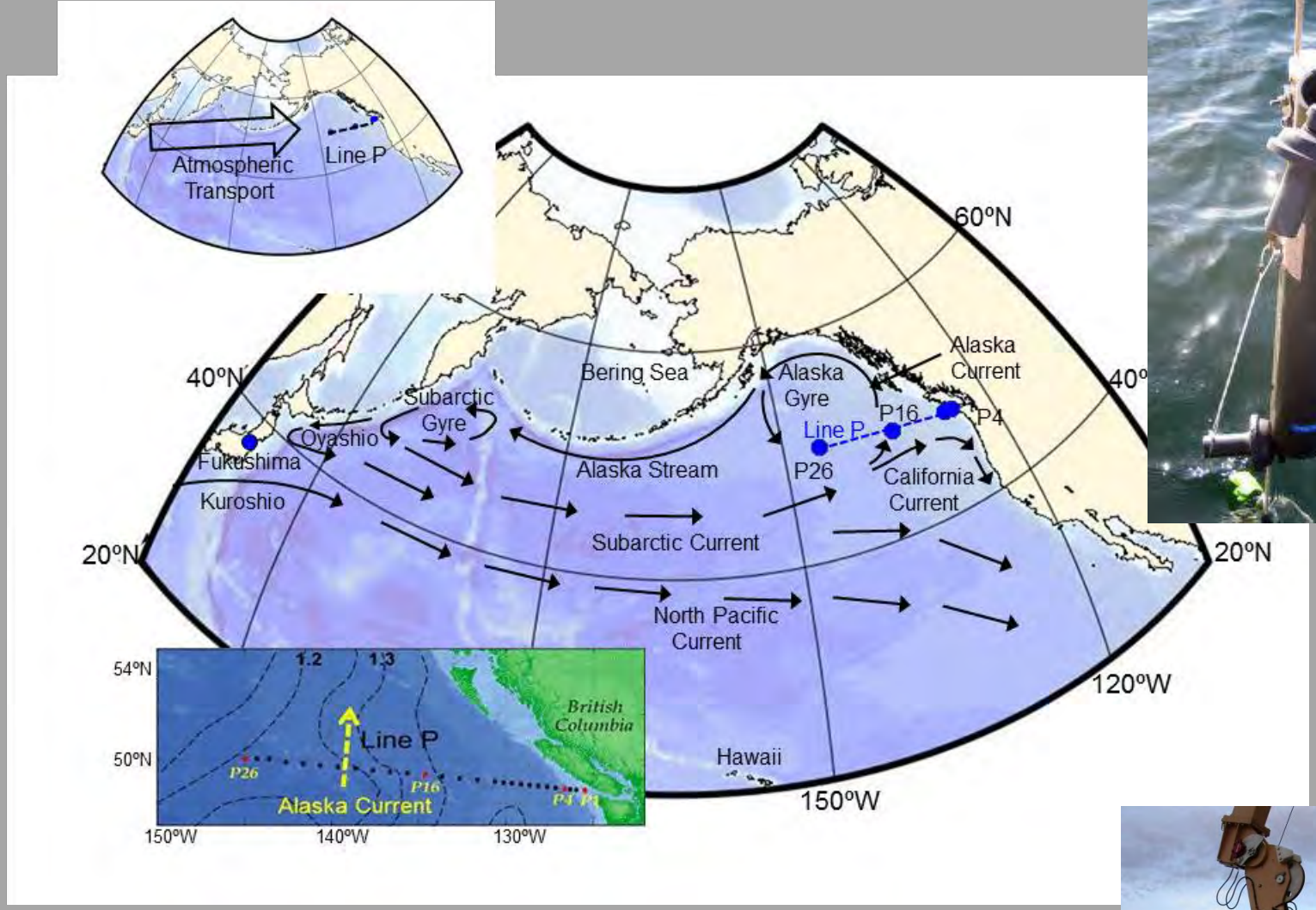




However, sensationalism represents legitimate public concerns.



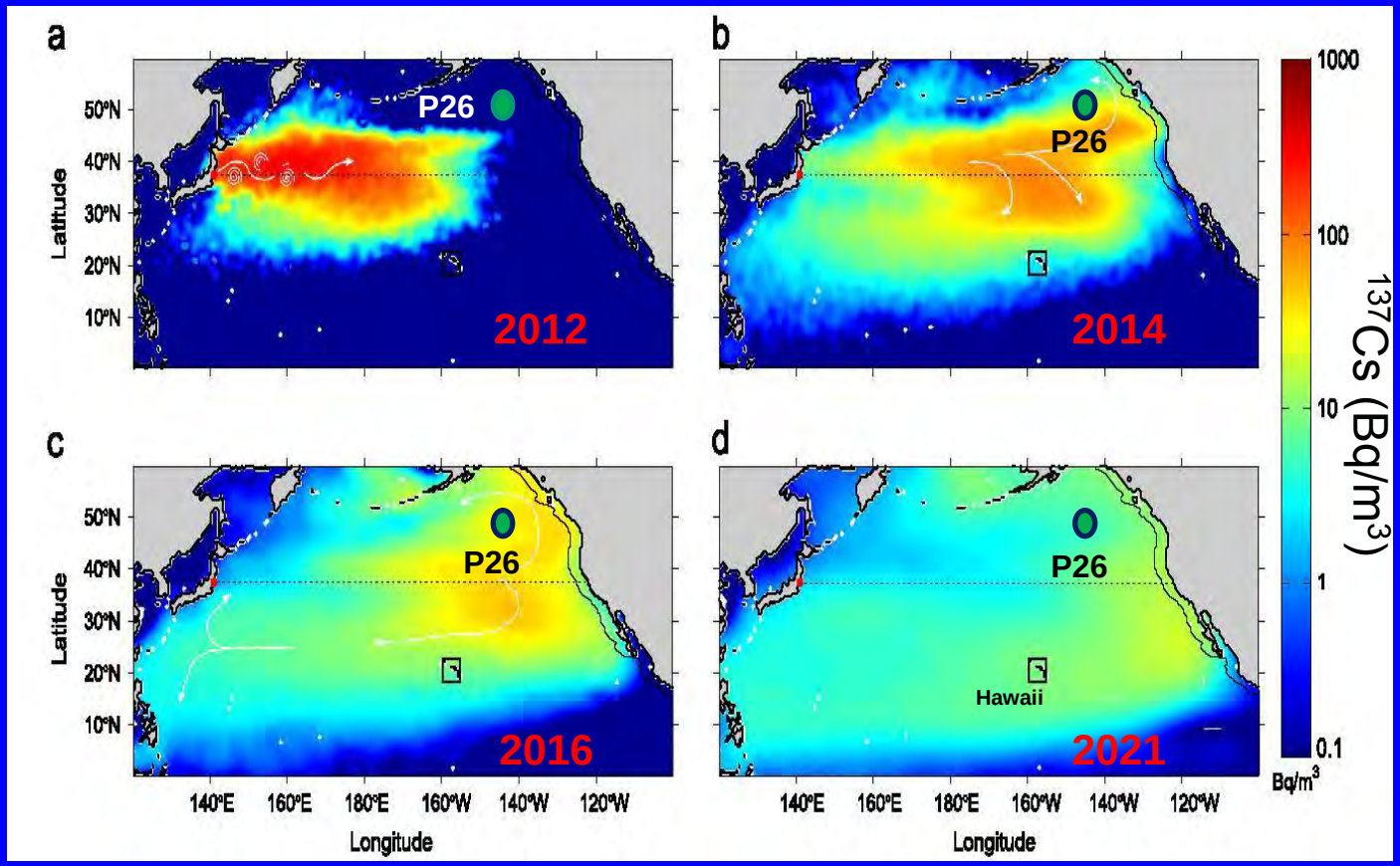
Current systems transported radioactivity from Fukushima Daiichi NPP eastward across Pacific and northward across Line P at the eastern edge of the Alaska gyre. *Upper inset*: Arrow shows northeastward direction for atmospheric transport of Fukushima radioactivity. *Lower inset:* Dashed curves are streamlines indicating strong northward flow in Alaska Current (yellow arrow).



Seawater samples of about 60 l collected using standard niskin bottles to depths of 500-1000 m on CCGS Tully.

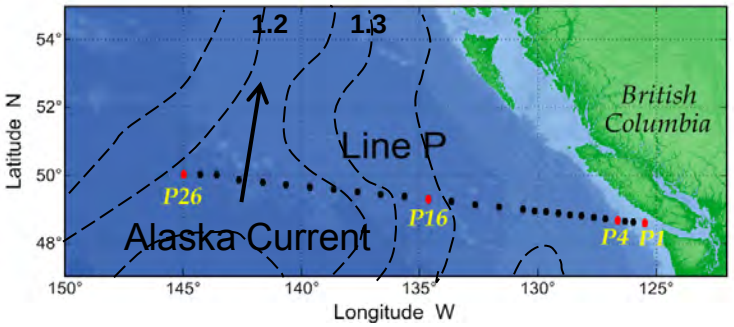
Seawater passed through KCFC resin cartridges at sea, shipped to BIO and analysed for ^{134}Cs,^{137}Cs using Ge hyperpure Gamma ray detectors.

Rossi et al. (2014) Ocean Circulation Model

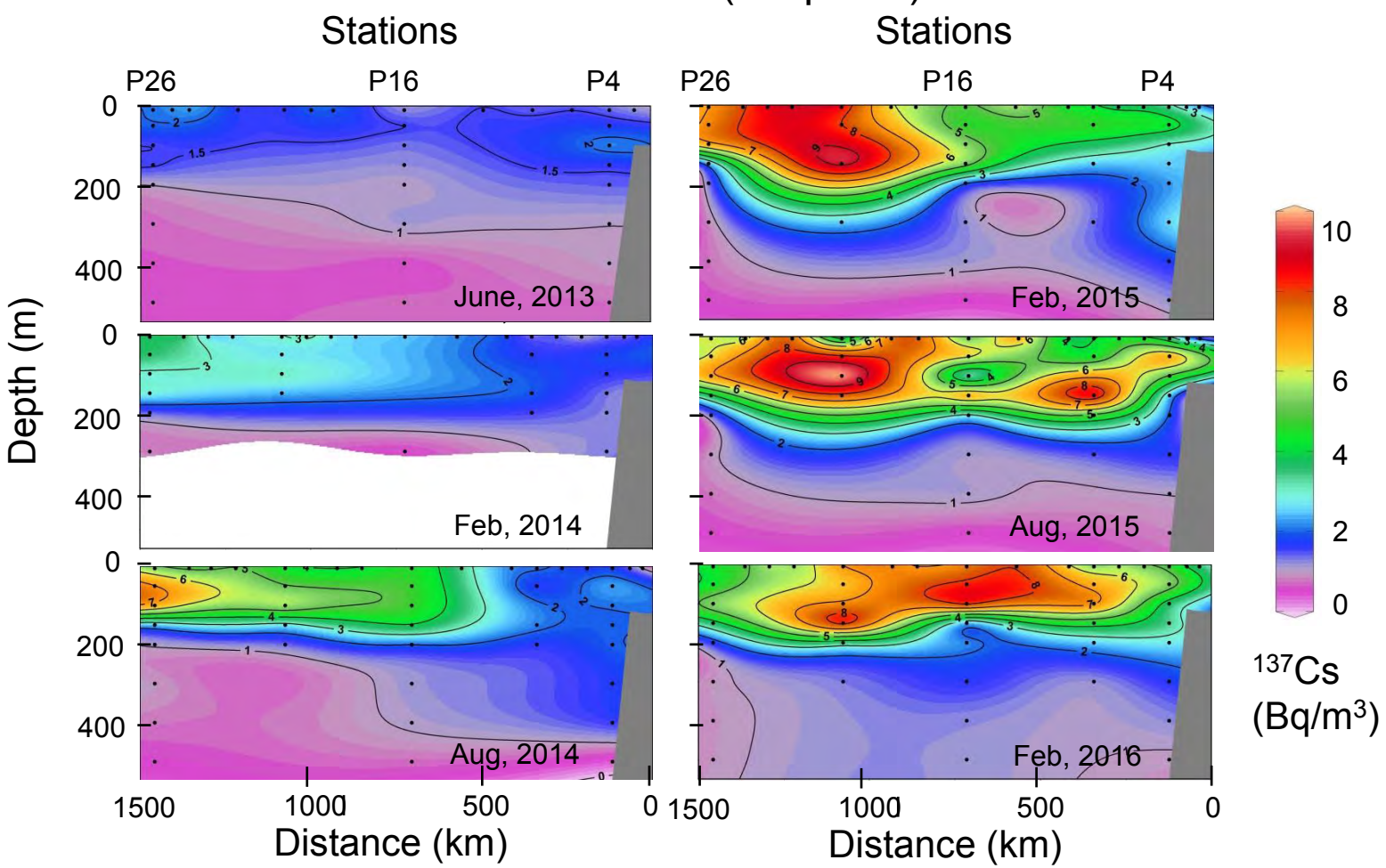


Maps show progression of ^{137}Cs surface water plume across Pacific for times of 1, 3, 5 and 10 years after accident. Green symbol is for Sta. P26. By 2016, major component of ^{137}Cs inventory has been transported from western to eastern North Pacific.

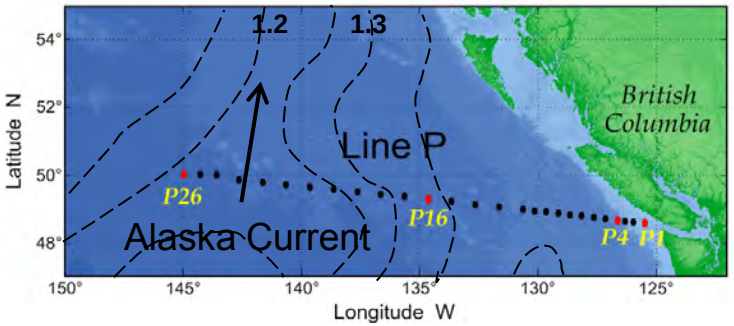
DFO Fukushima Monitoring Program



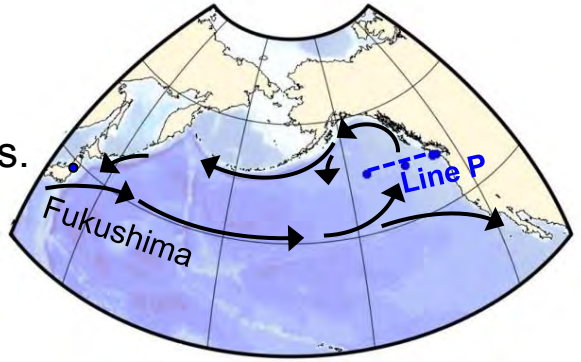
Time series of ^{137}Cs sections on Line P shows signal increasing with time and spreading eastwards towards BC coast. ^{137}Cs flow stalls in weak, disorganized flow regime east of Sta. 16 where sea surface height streamlines (left panel) show northward flow in Alaska Current.

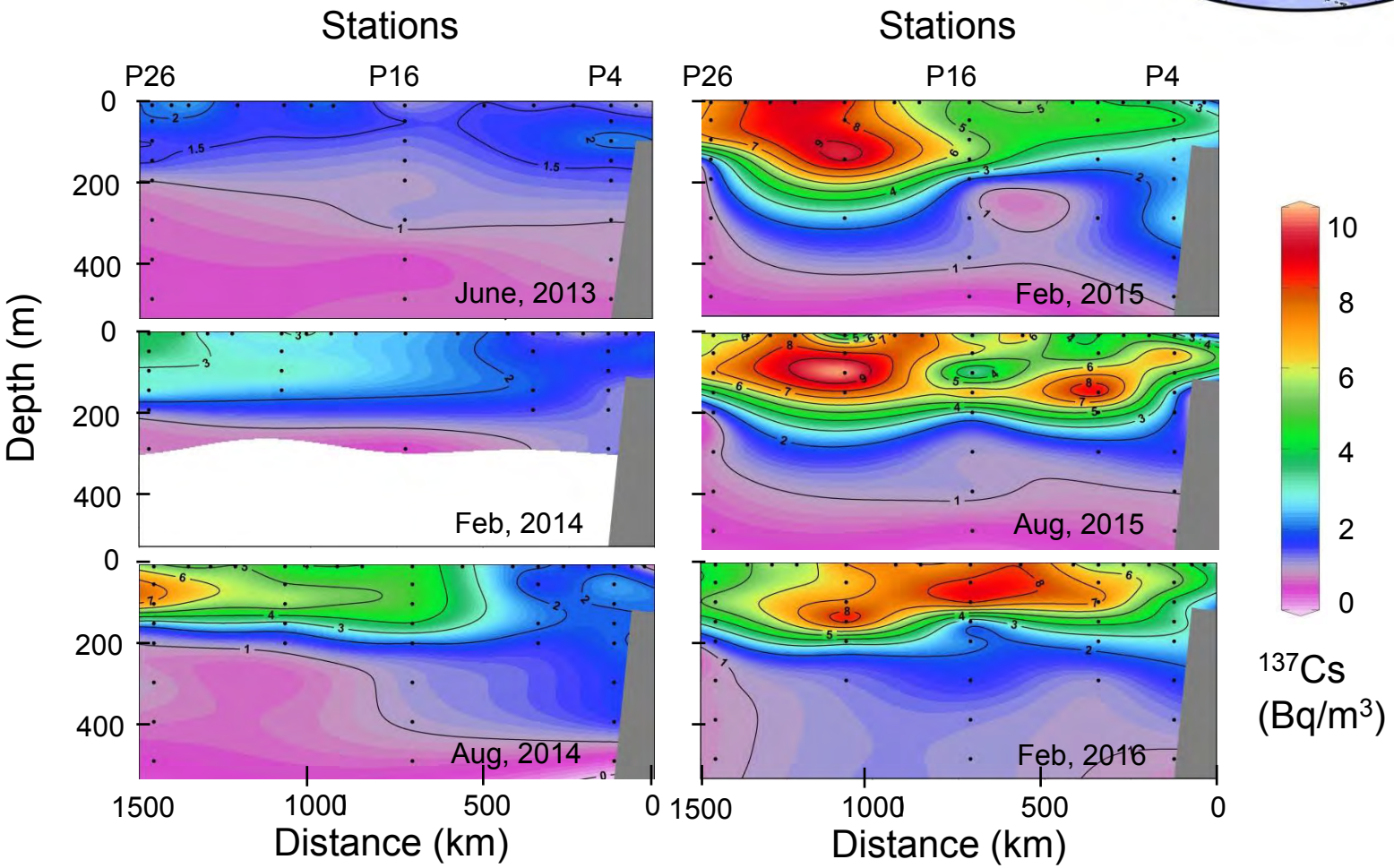


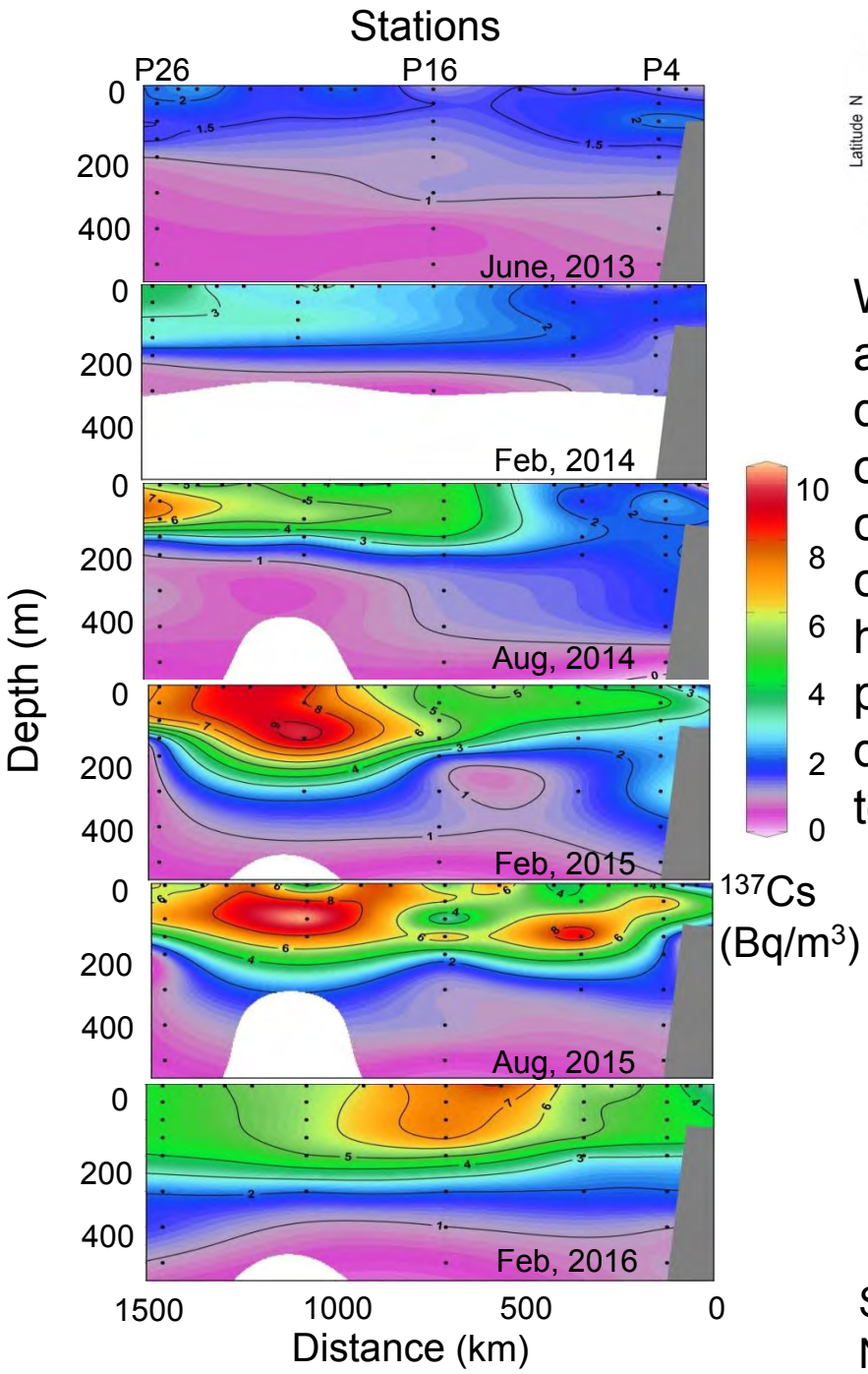
DFO Fukushima Monitoring Program

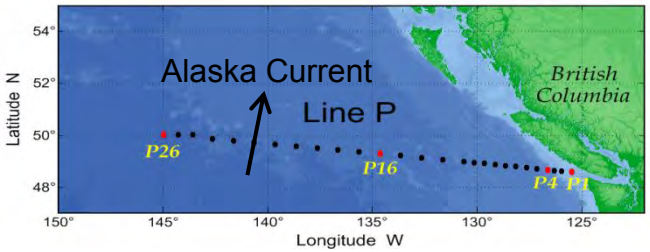


Transport across Pacific to Line P takes about 2 years.

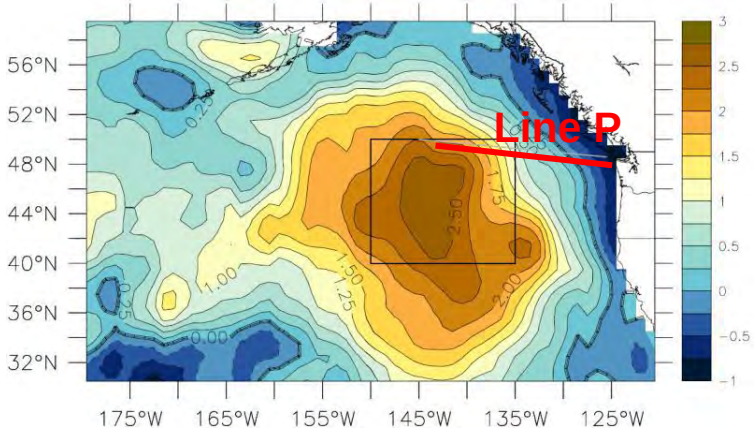




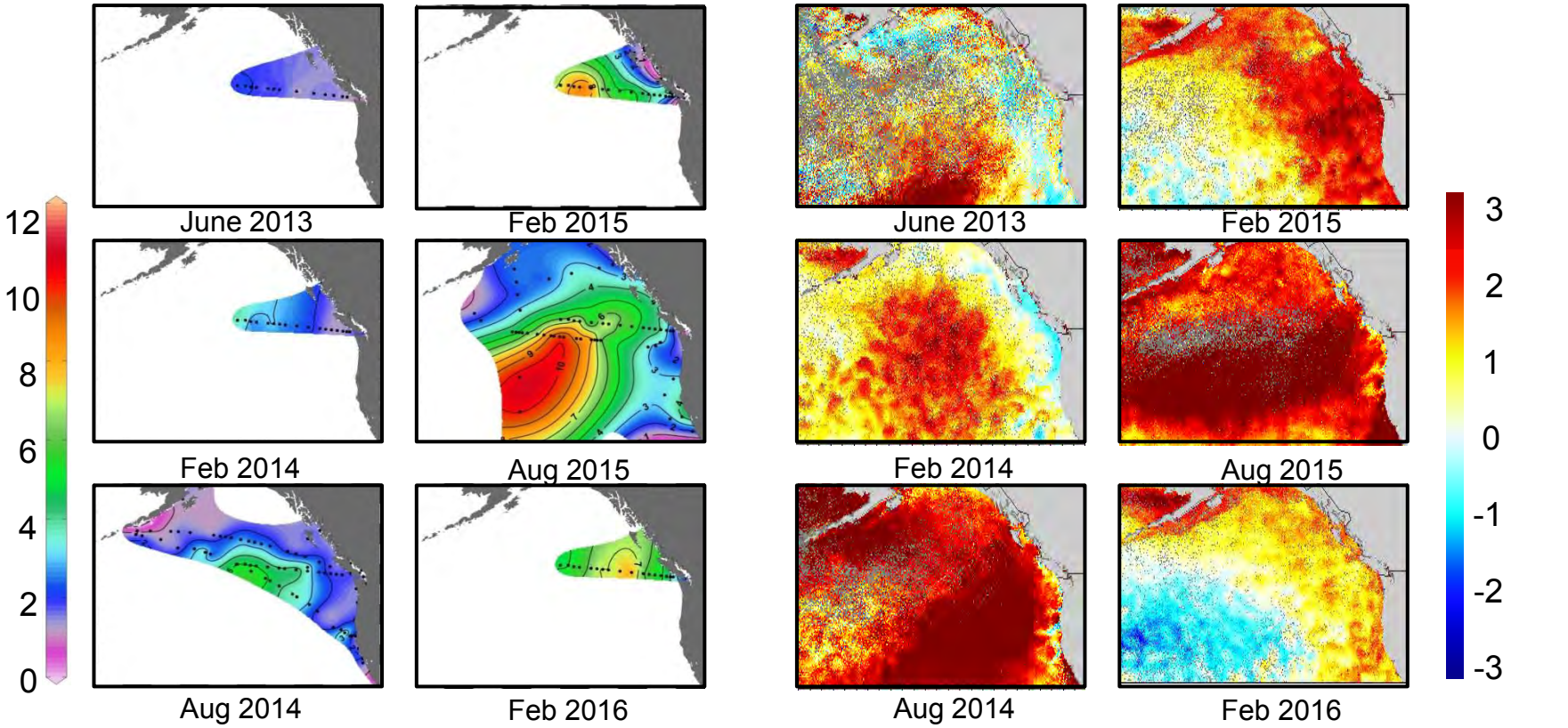




Warm sea surface temperature (SST) anomaly popularly known as the “Blob” developed in 2012-2014 from formation of high atmospheric pressure ridge over continental margin. The Blob was congruent with the offshore “pool” of high Fukushima ^{137}Cs. By 2015 the pressure ridge had dissipated, the Blob diminished and the ^{137}Cs signal released towards coast.



Sea surface temperature anomaly (°C) in NE Pacific Ocean - February 2014.

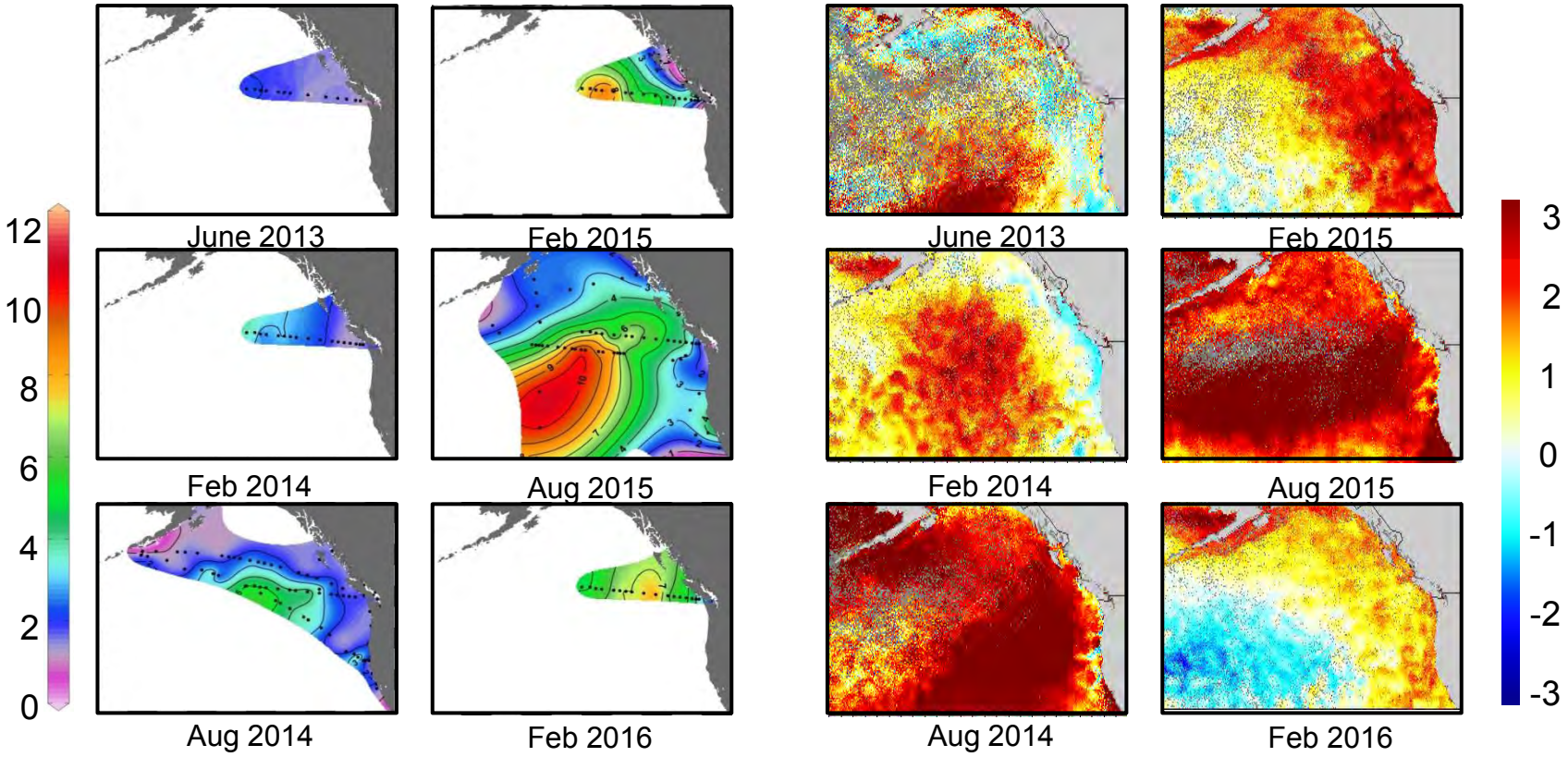


^{137}Cs (Bq/m^3)

Left two columns: ^{137}Cs surface water distributions (2013-2016) show spatial evolution of the Fukushima plume as it nears the Canadian coastline.

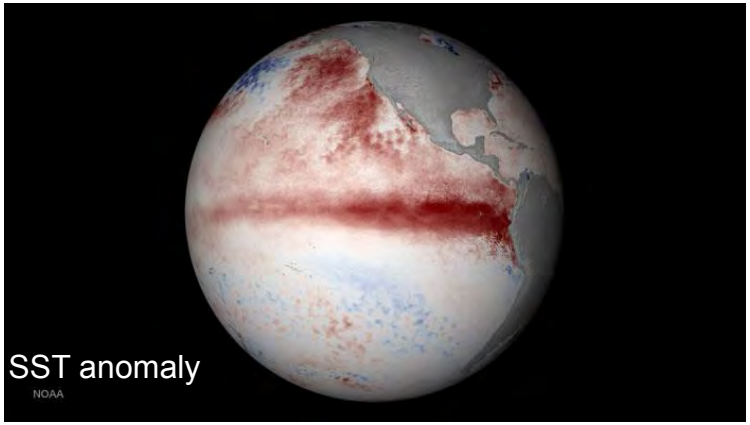
SST Anomaly (ºC)

Right two columns: SST anomaly distributions for same time period outline the development of the warm “Blob” which occupied the same water masses as Fukushima tracer patch and whose configuration is shaped by the anomalously high atmospheric pressure system over the northeast Pacific in 2013-14.

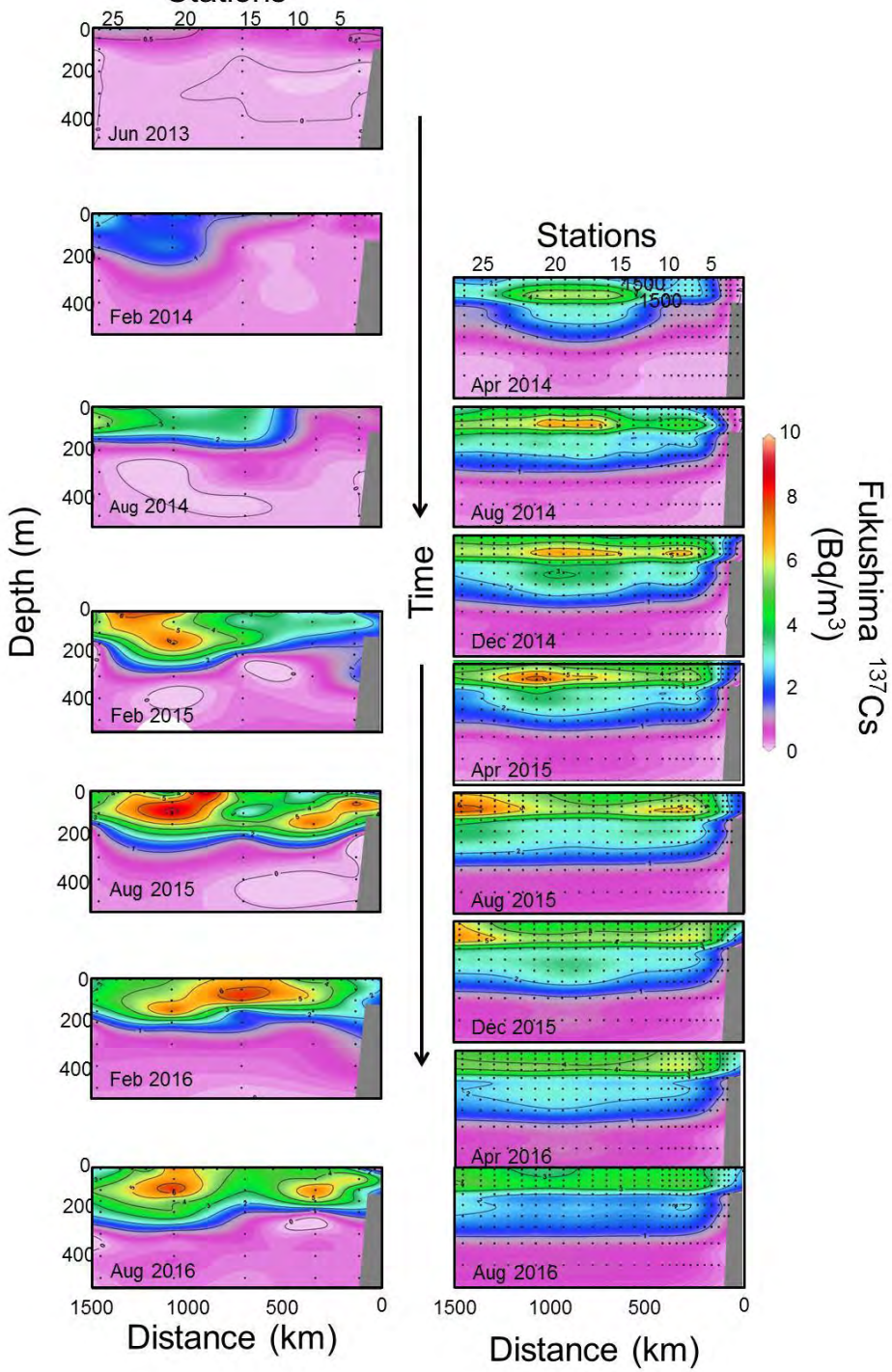


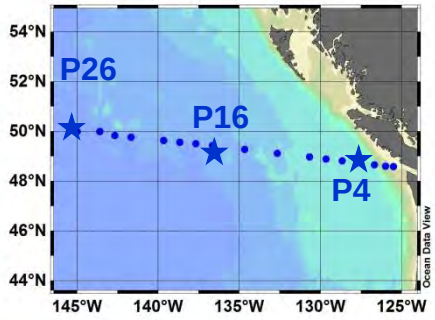
^{137}Cs (Bq/m^3)

SST Anomaly (ºC)



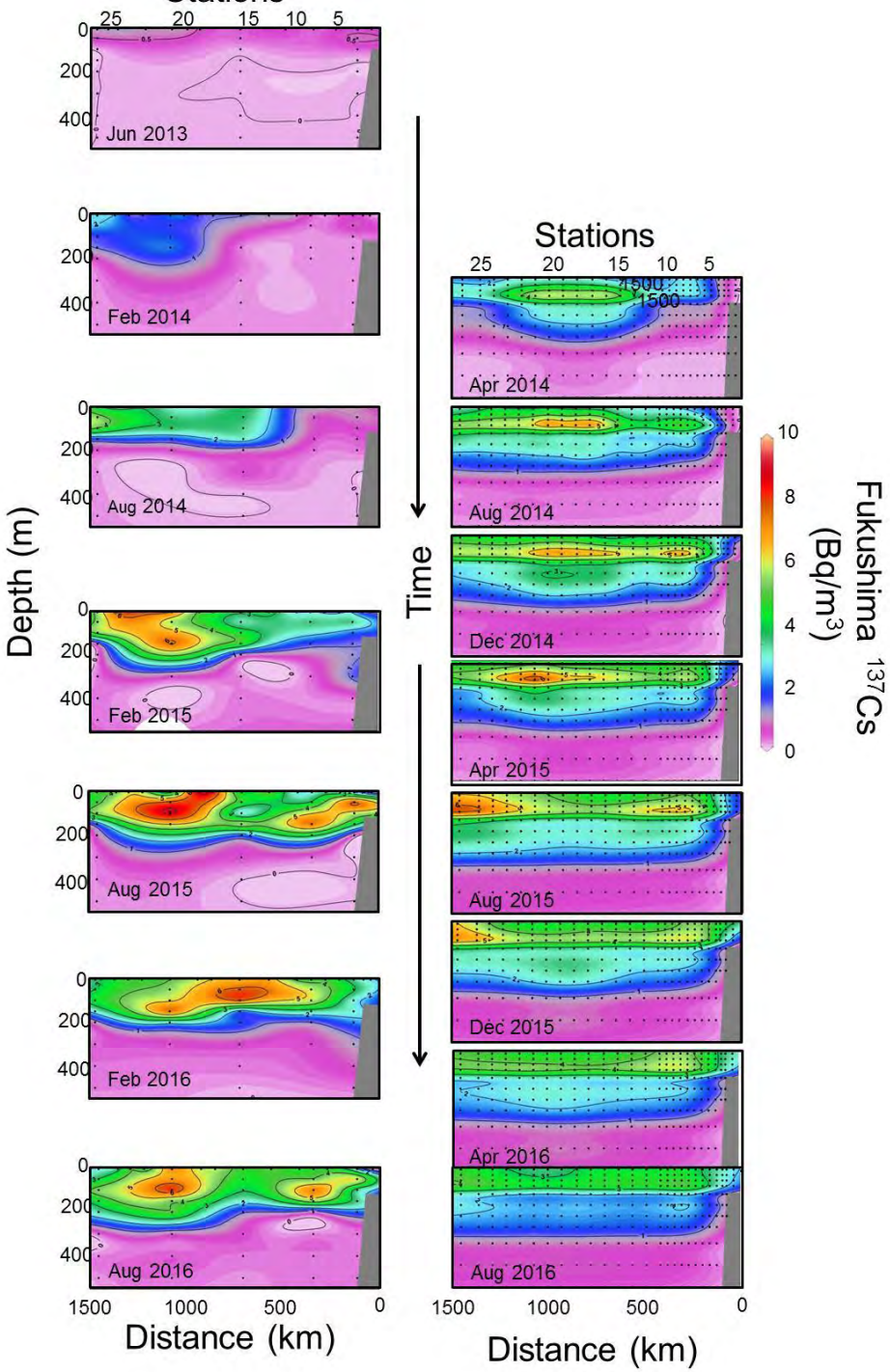
By August 2015; Blob had elongated southeastward and second El Nino related warm SST anomaly had developed near equator.

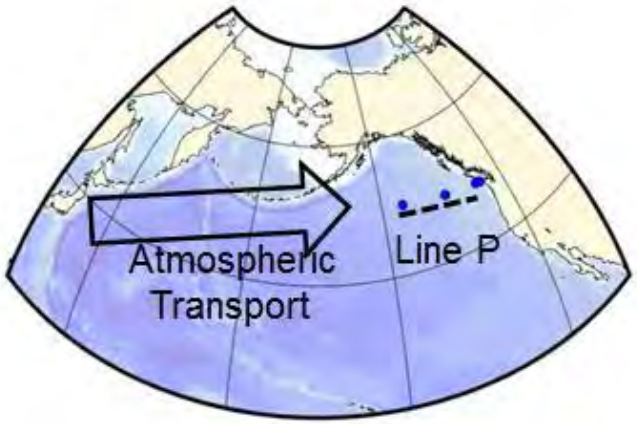




Left Panel: Line P time series sections for Fukushima ^{137}Cs.

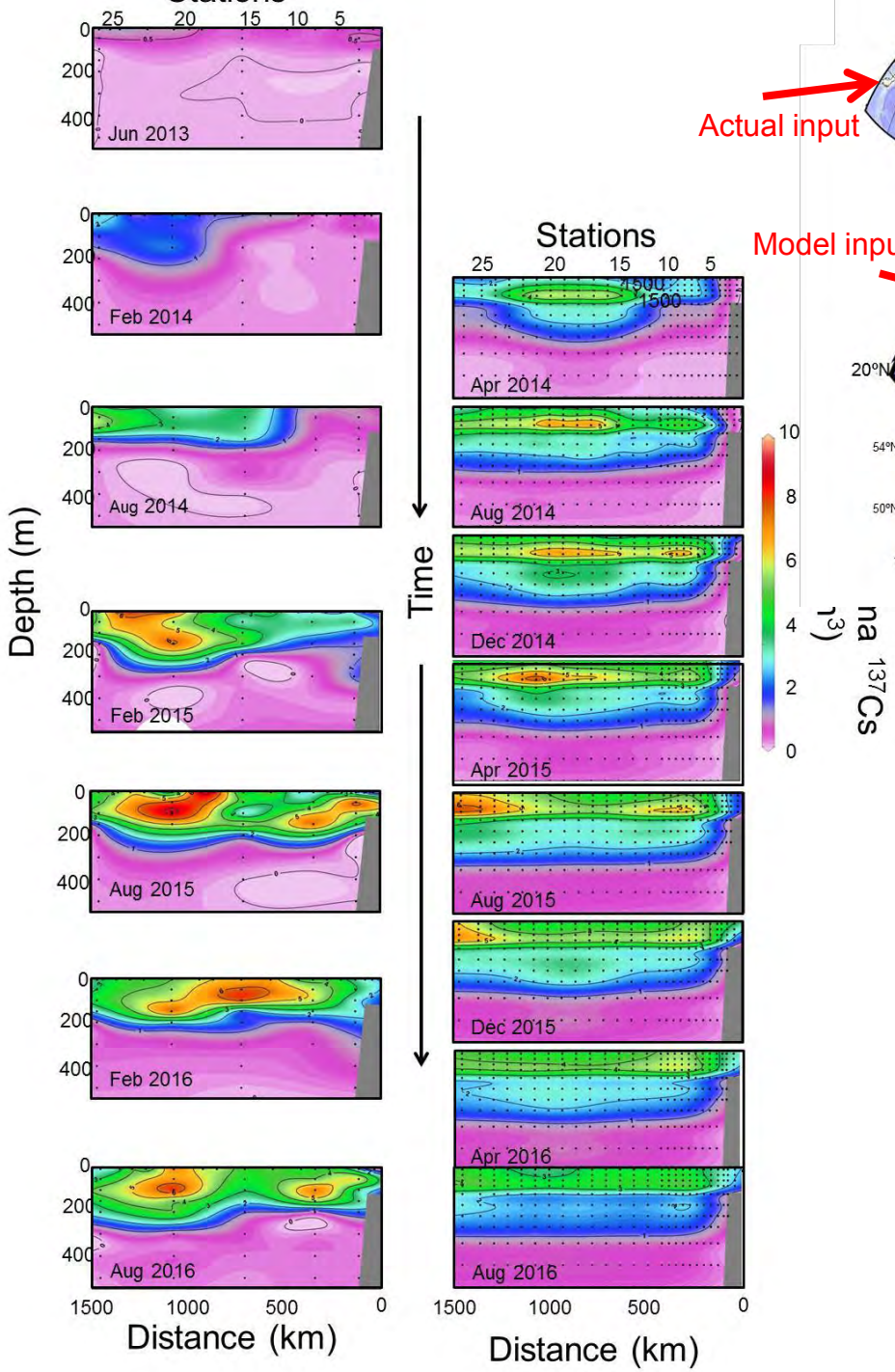
Right Panel: Line P ^{137}Cs time series simulations (Rossi et al., 2014) assuming Fukushima point source are generally consistent with main features of the measured results,

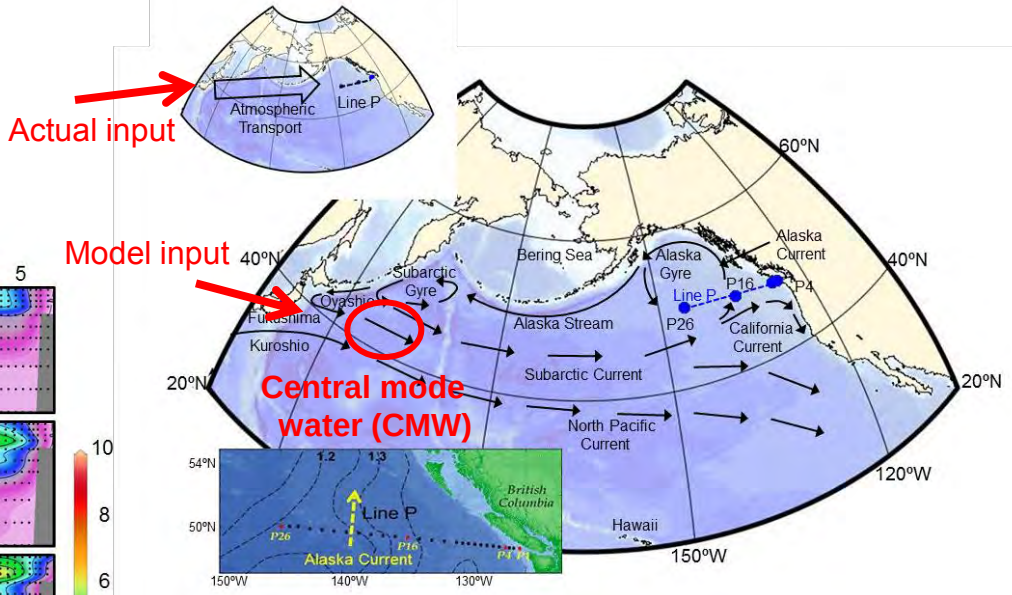




Right Panel: Line P ^{137}Cs time series simulations (Rossi et al., 2014) assuming Fukushima point source are generally consistent with main features of the measured results, **except**:

1. Measured signal arrives first at Sta. P26 owing to initial atmospheric transport.

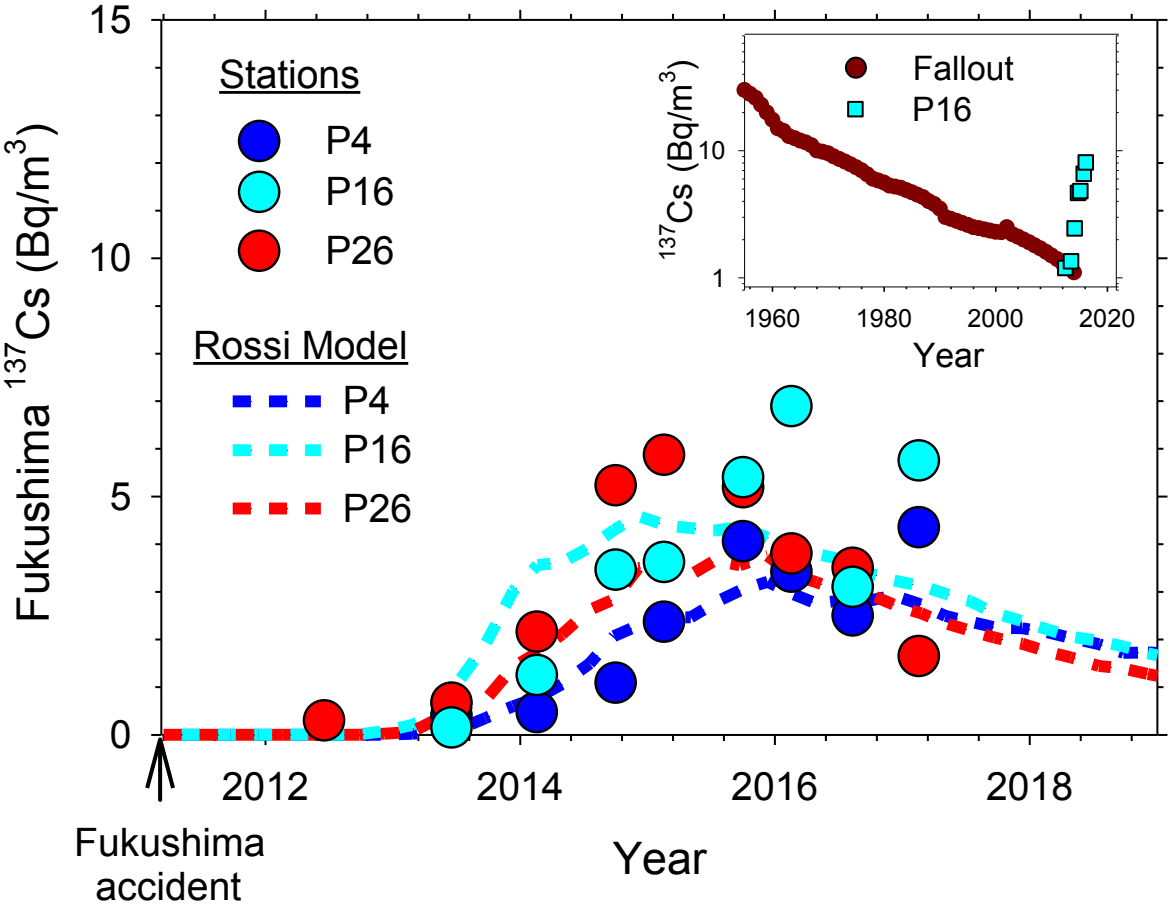


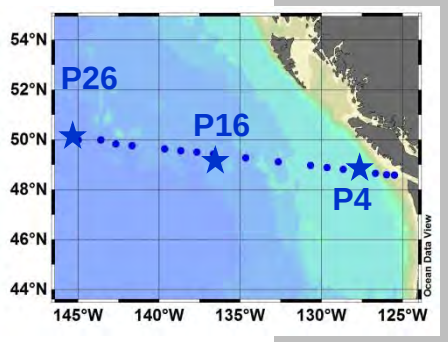


Right Panel: Line P ^{137}Cs time series simulations (Rossi et al., 2014) assuming Fukushima point source are generally consistent with main features of the measured results, **except:**

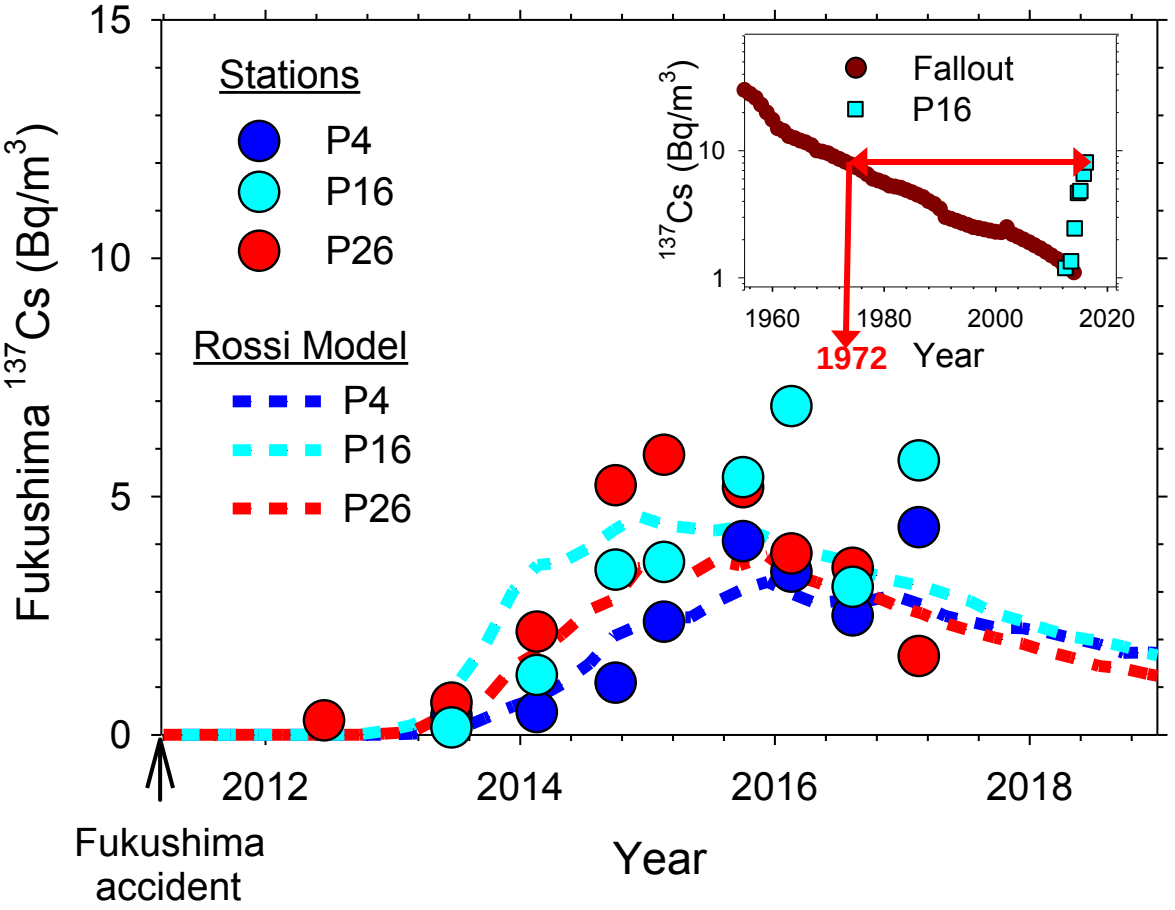
1. Measured signal arrives first at Sta. P26 owing to initial atmospheric transport.

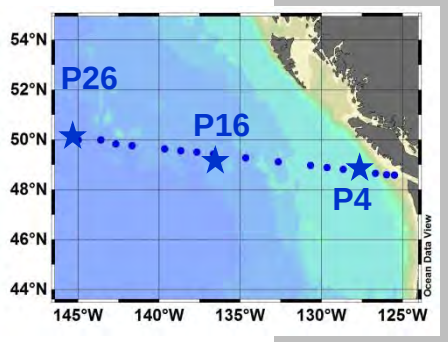
2. Model signal extends deeper than measured signal owing to excessive influence of mode water in simulation.





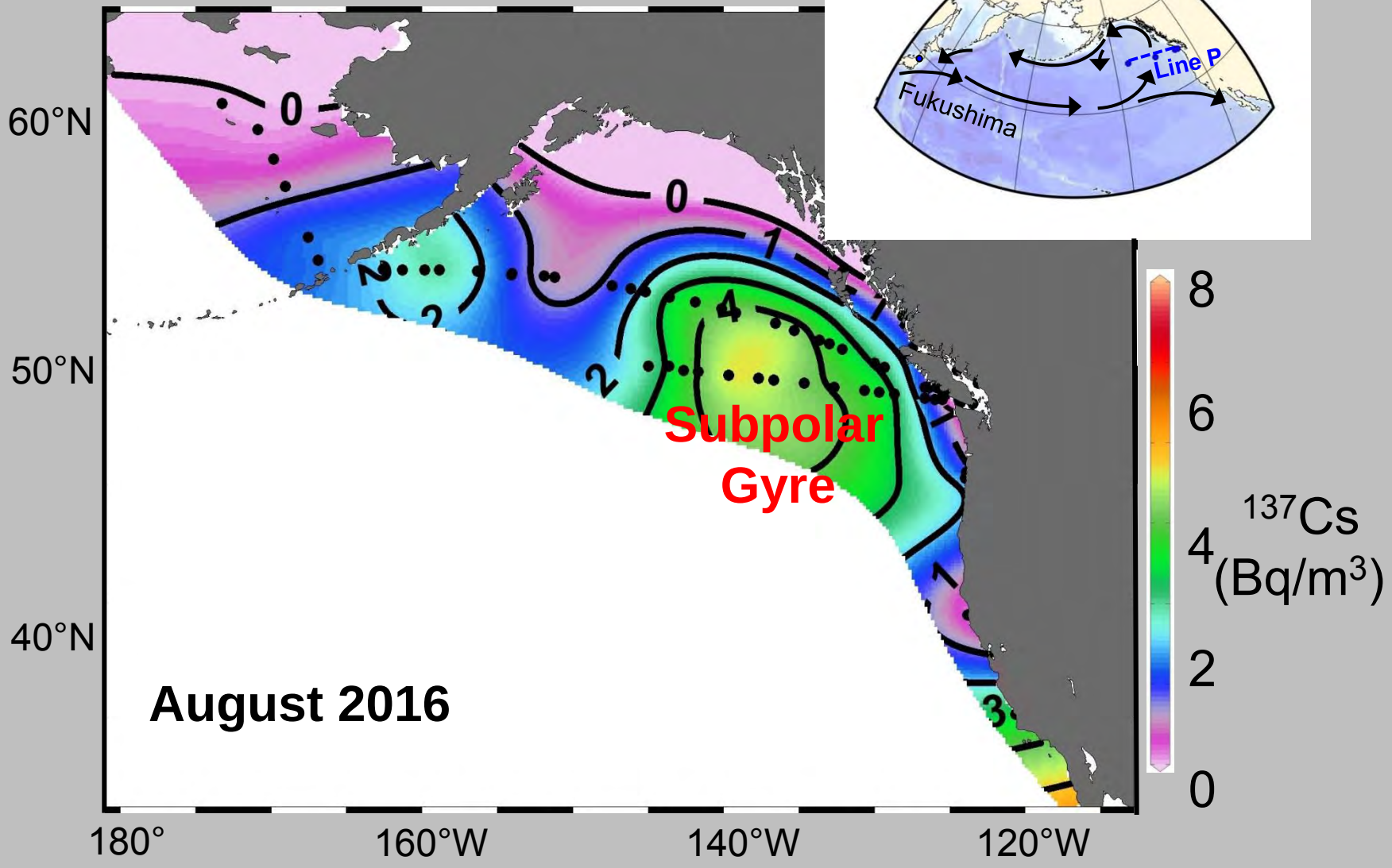
Time series for Fukushima ^{137}Cs (symbols) in surface water (Stas. P4, P16 and P26) compared to Rossi model results (dashed lines). By February 2017, ^{137}Cs levels had begun to decrease at Stas. P16 and P26 in interior waters, but were still at maximum levels at Sta. P4 over continental shelf.



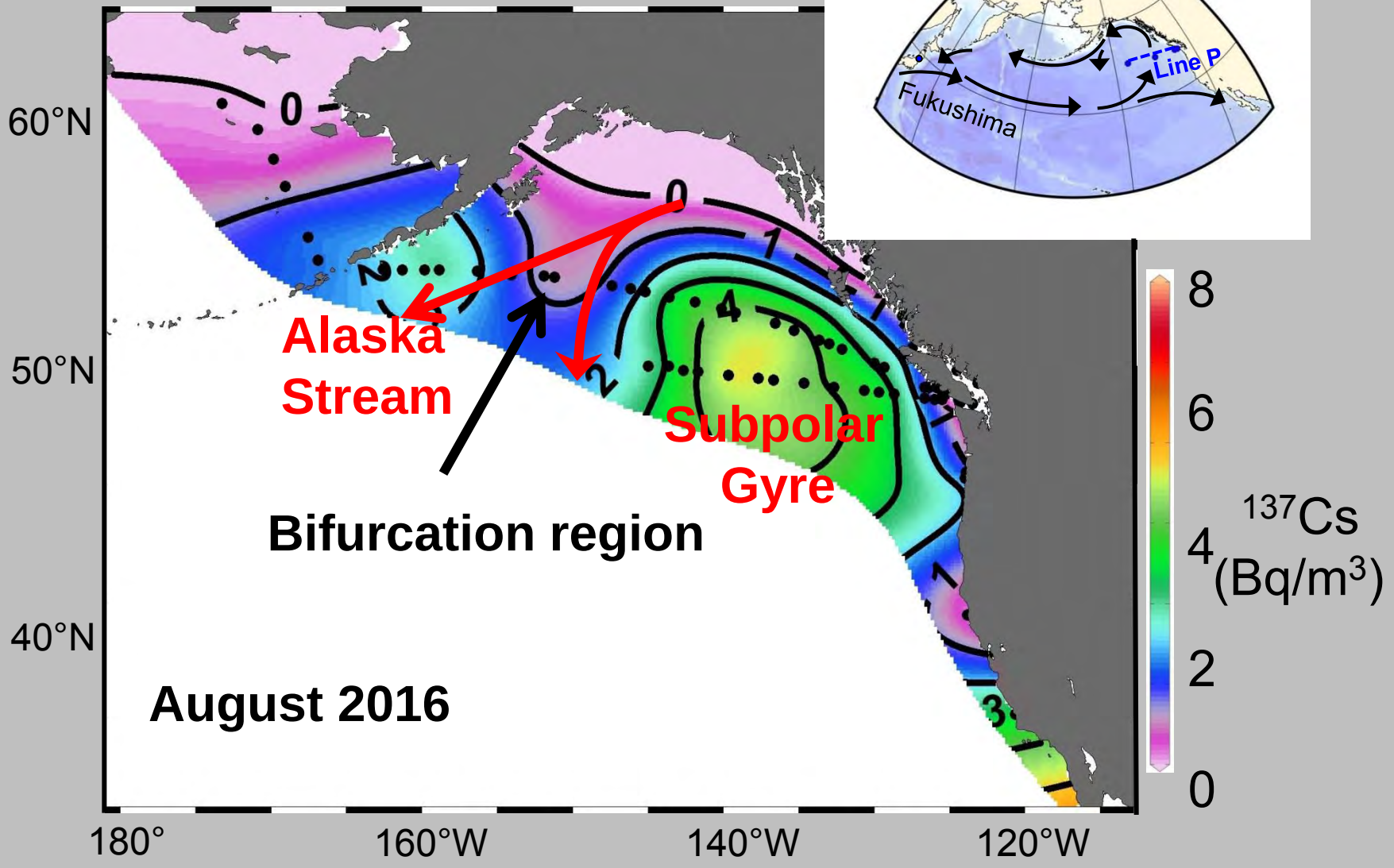


Time series for Fukushima ^{137}Cs (symbols) in surface water (Stas. P4, P16 and P26) compared to Rossi model results (dashed lines). By February 2017, ^{137}Cs levels had begun to decrease at Stas. P16 and P26 in interior waters, but were still at maximum levels at Sta. P4 over continental shelf. **Inset: model ^{137}Cs results are compared to historical record for ^{137}Cs fallout levels in North Pacific Ocean. Fukushima has returned North Pacific levels to those produced by fallout in 1972.**

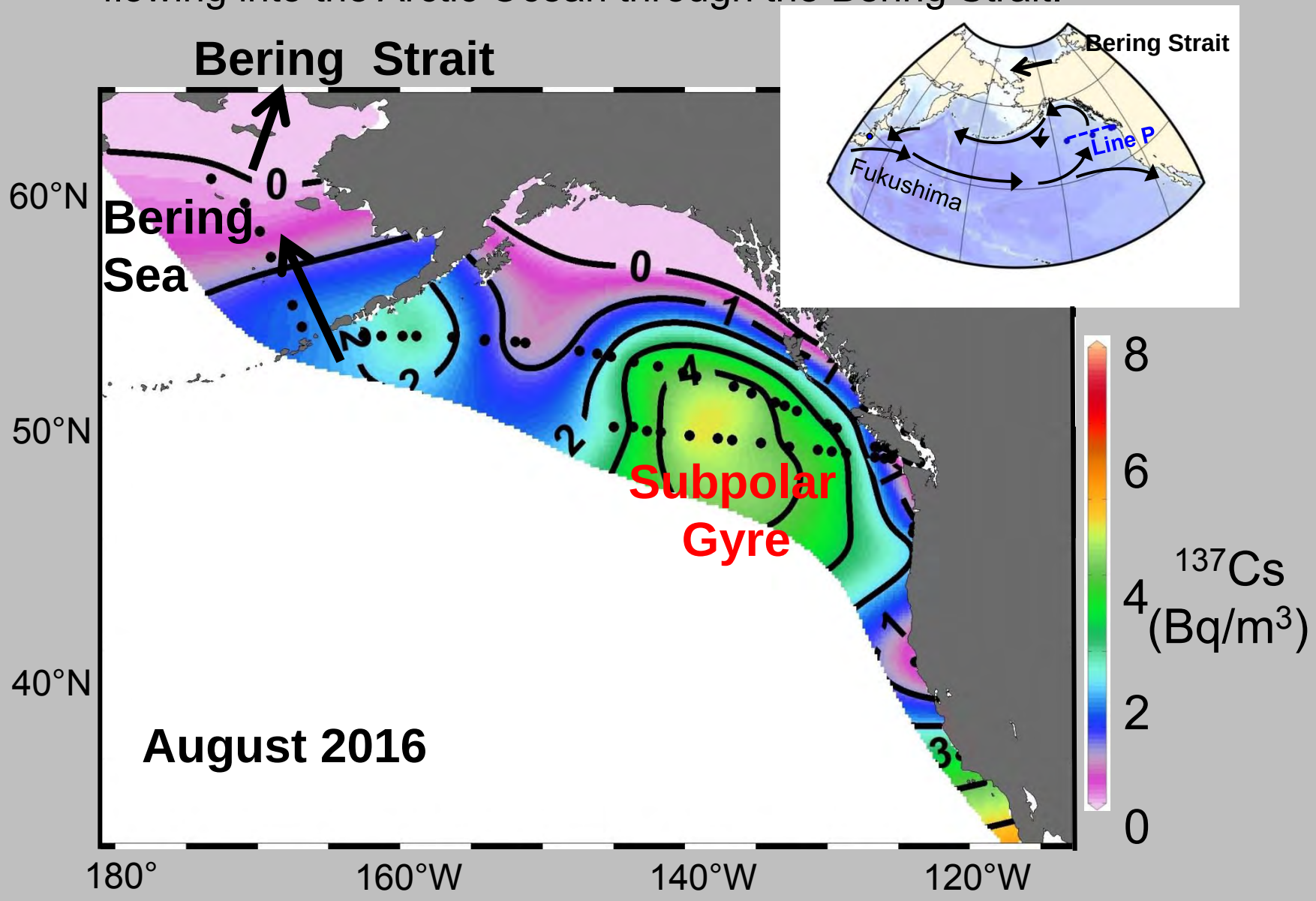
Recent results show two maxima in ^{137}Cs surface water distributions.



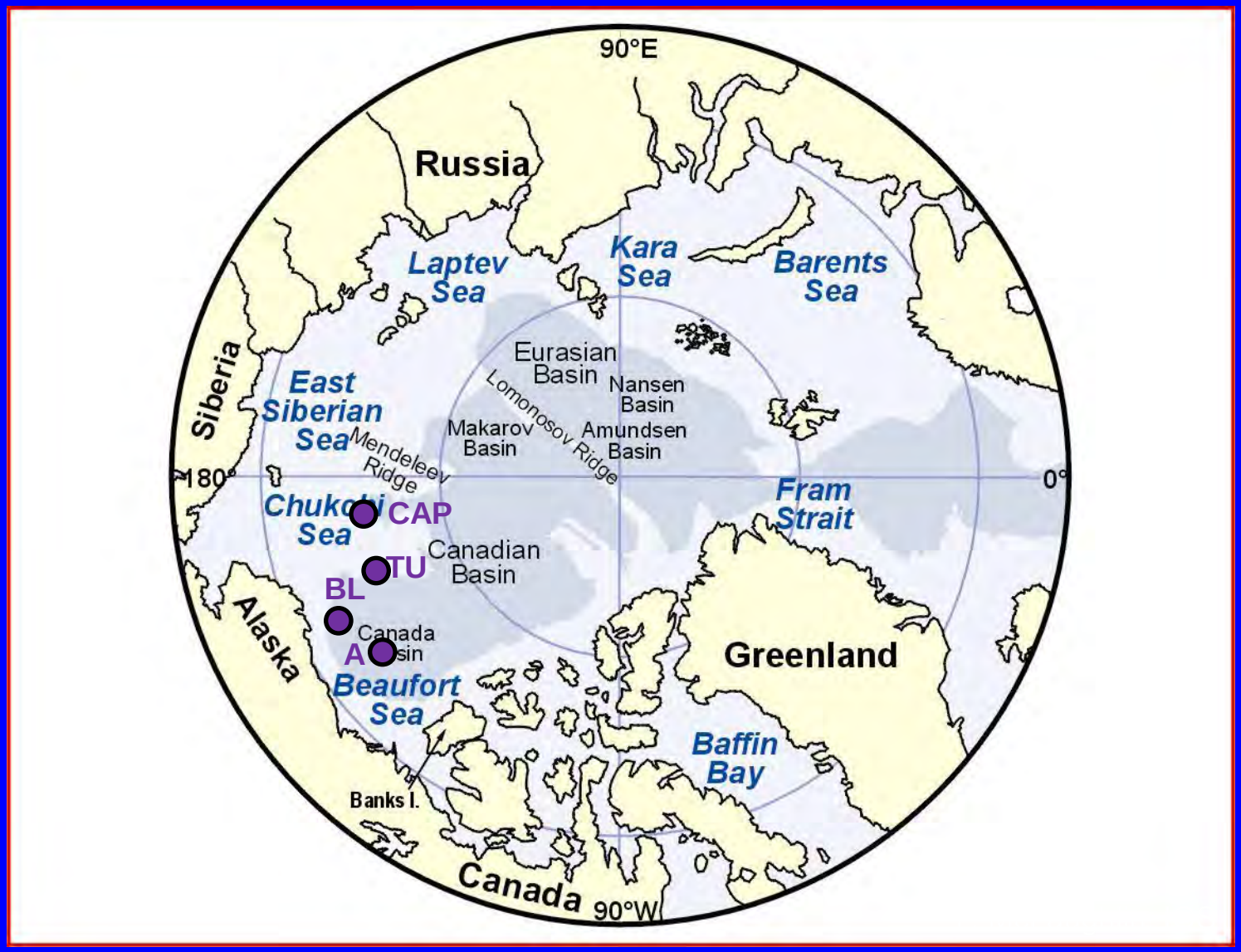
Alaska Current bifurcates into westward flowing Alaska Stream and western edge of Subpolar Gyre, each having Fukushima ^{137}Cs signal.



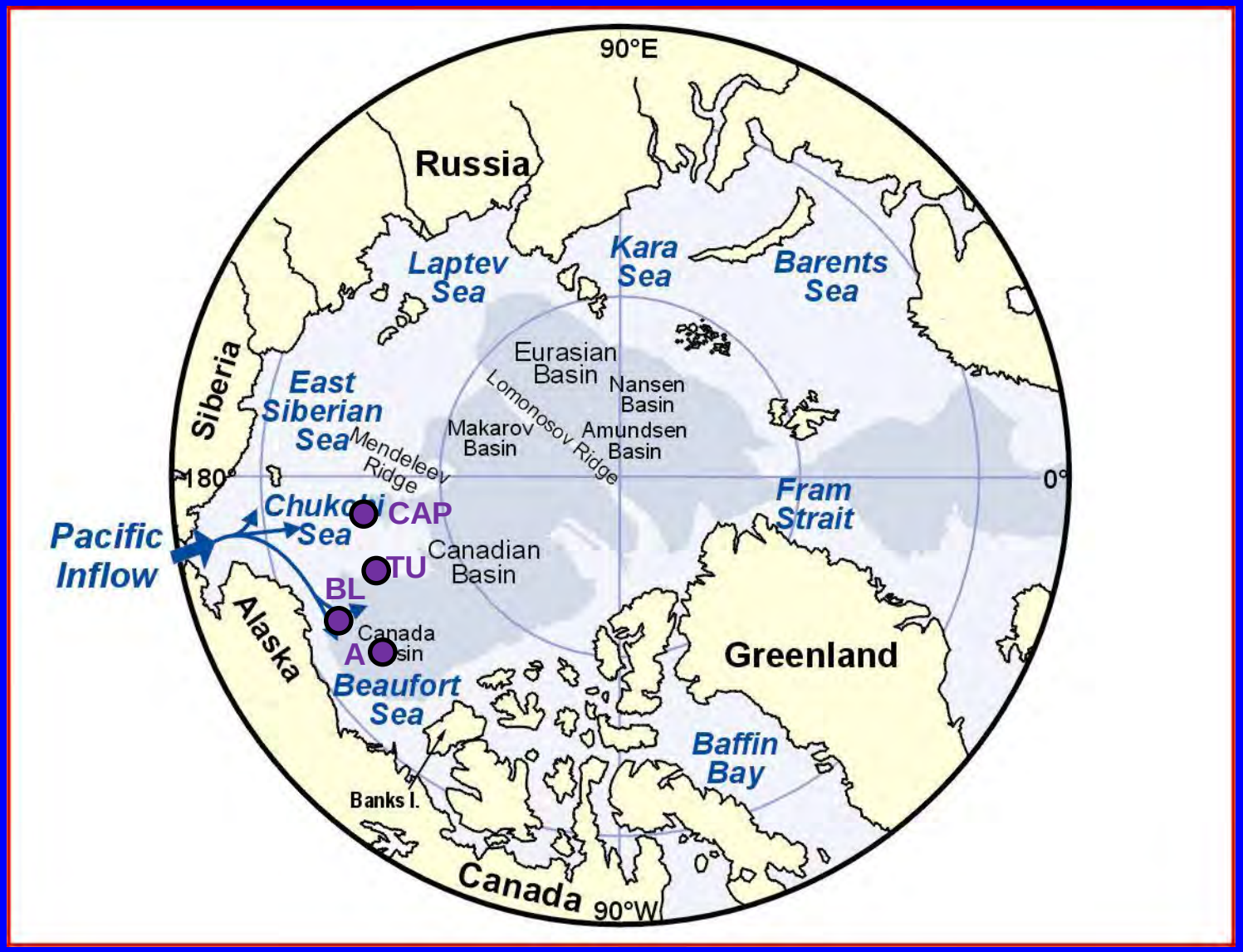
Fukushima tracer signal now entering Bering Sea and probably flowing into the Arctic Ocean through the Bering Strait.

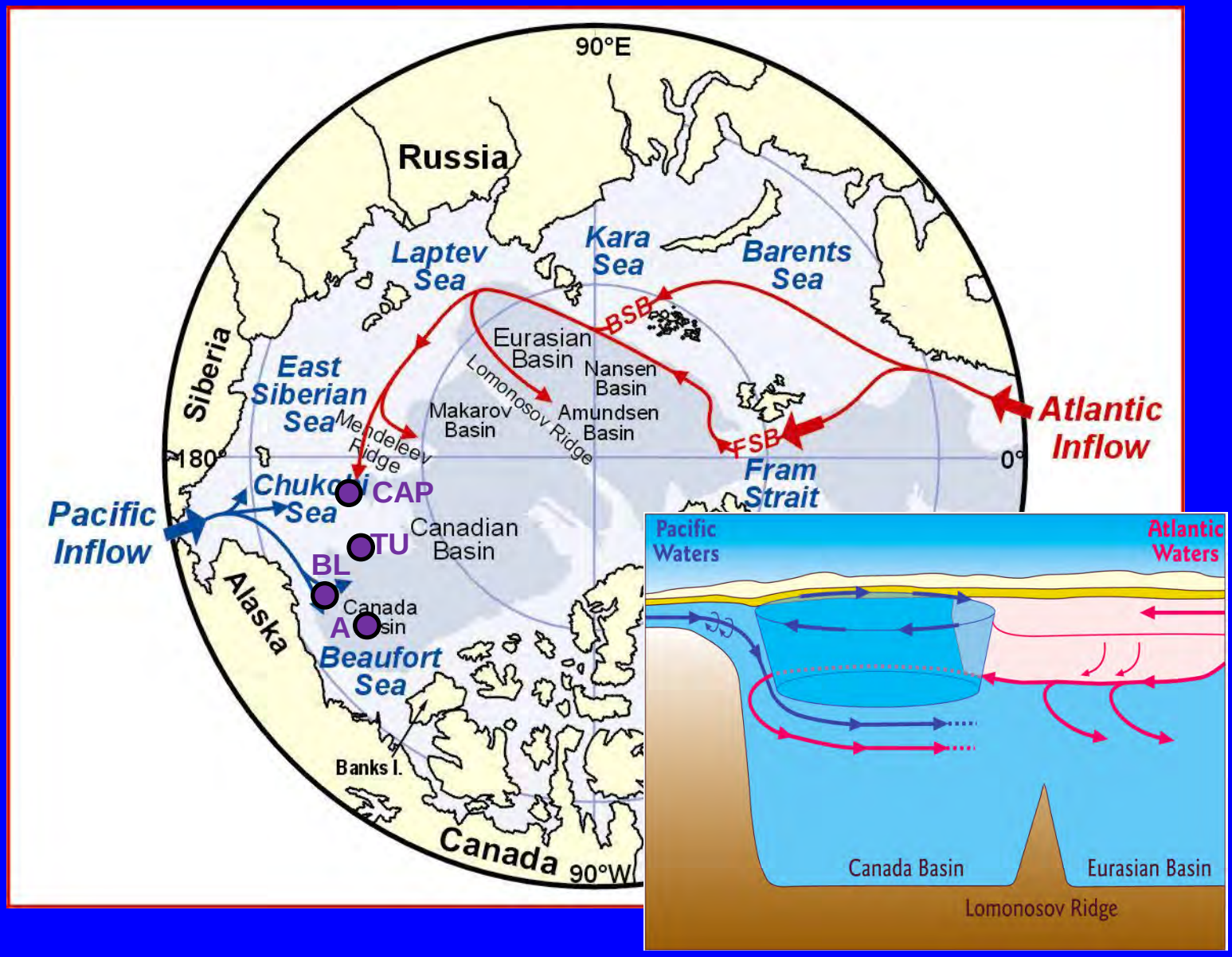


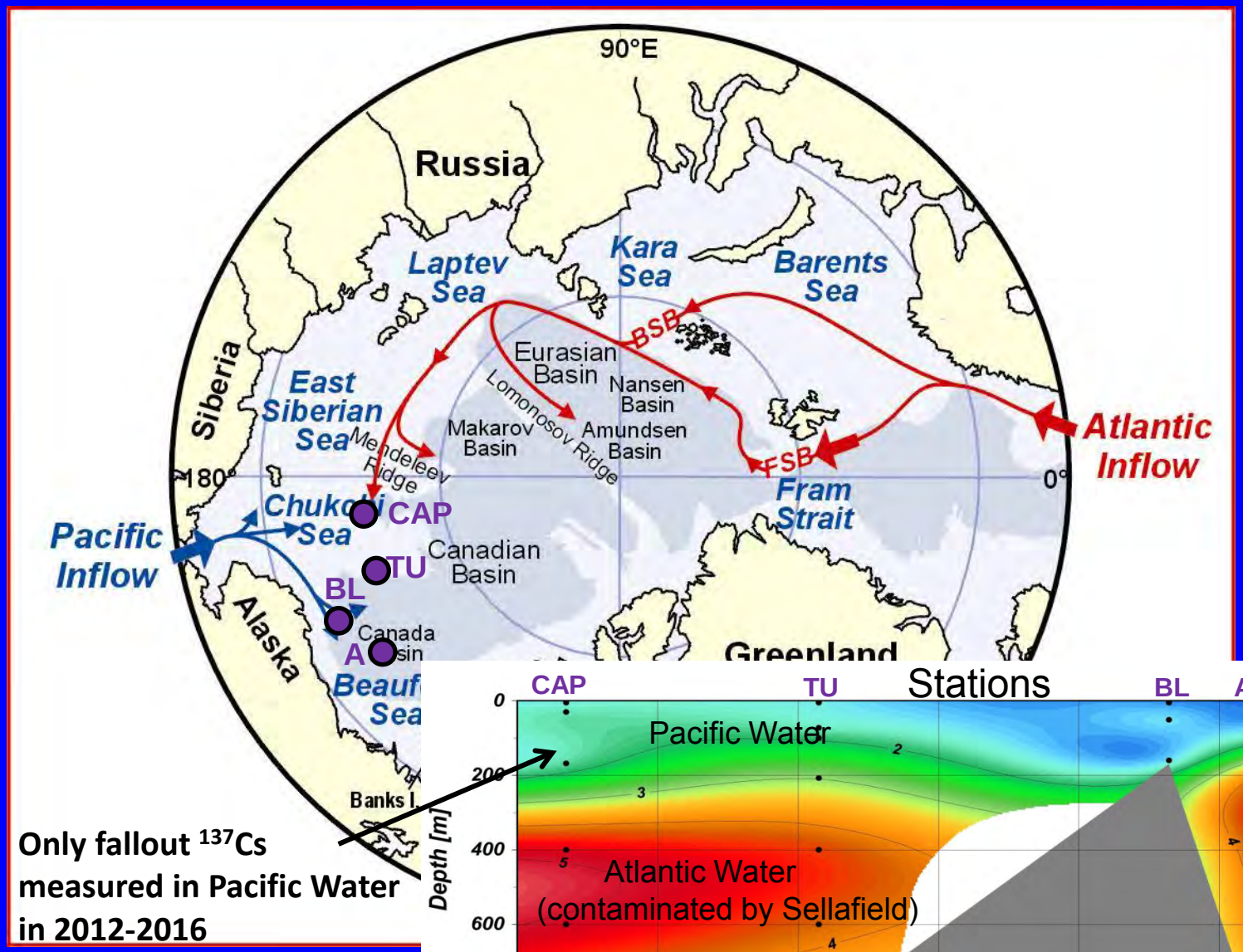
Is Fukushima ^{137}Cs a new tracer in Arctic Ocean?



JOIS Missions (*Bill Williams; IOS*) – 2012-2017

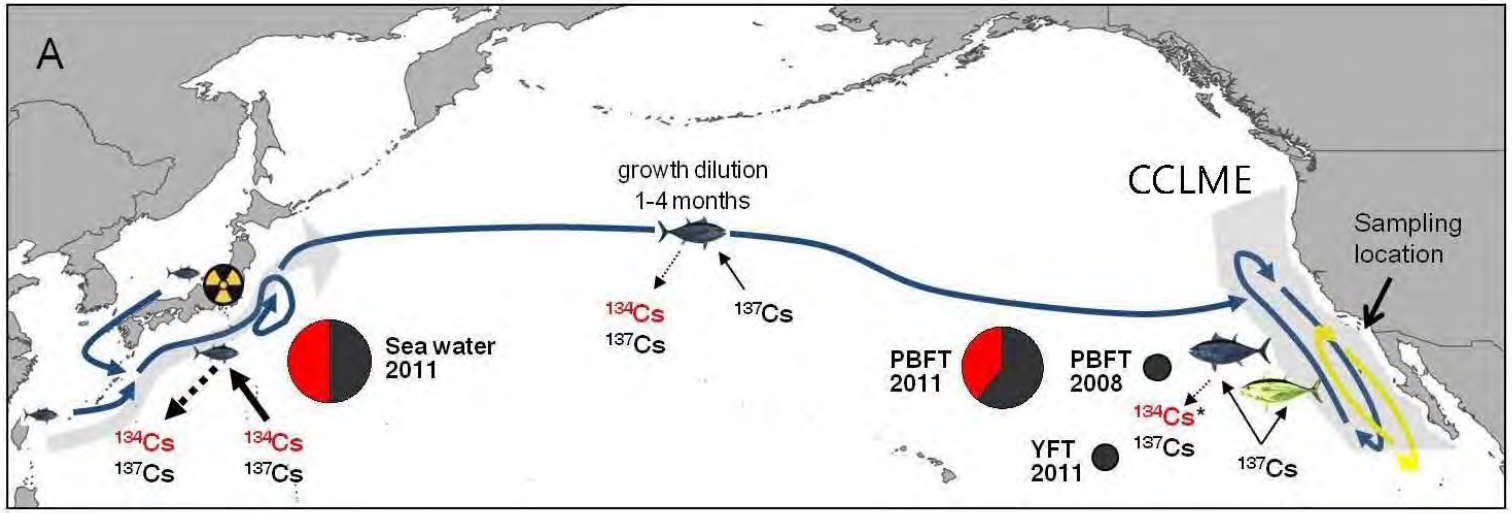

90°E
Russia
Laptev Sea
Kara Sea
Barents Sea
Siberia
East Siberian Sea
Eurasian Basin
Nansen Basin
Lomonosov Ridge
Makarov Basin
Amundsen Basin
Mendeleev Ridge
180°
0°
Fram Strait
Pacific Inflow
Chukchi Sea
CAP
TU
BL
A
Canadian Basin
Canada Basin
Alaska
Greenland
Beaufort Sea
Baffin Bay
Banks I.
Canada
90°W


90°E
Russia
Laptev Sea
Kara Sea
Barents Sea
BSB
Eurasian Basin
Nansen Basin
Lomonosov Ridge
Makarov Basin
Amundsen Basin
Mendeleev Ridge
East Siberian Sea
Siberia
180°
0°
FSB
Fram Strait
Atlantic Inflow
Pacific Inflow
Chukchi Sea
CAP
TU
BL
A
Canadian Basin
Canada Basin
Alaska
Beaufort Sea
Banks I.
Canada
90°W
Pacific Waters
Atlantic Waters
Canada Basin
Eurasian Basin
Lomonosov Ridge



Only fallout ^{137}Cs measured in Pacific Water in 2012-2016

What about biological uptake and trans-Pacific transport?



Fisher et al., 2012

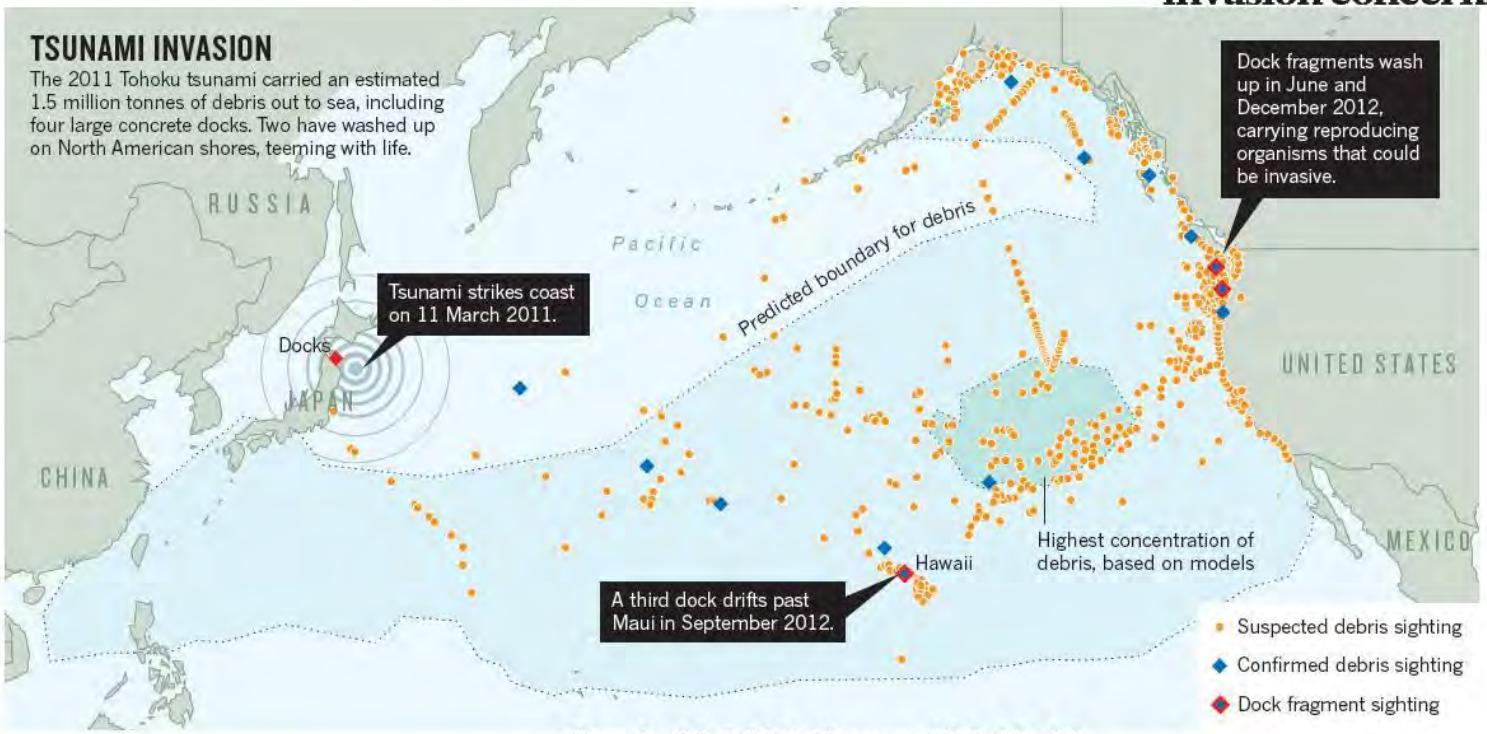
Pacific bluefin tuna spawn off Japan, then migrate across Pacific to the California Current ecosystem – ^{134}Cs from Fukushima was measured in all tuna captured in late 2011 off California; transit time was 4 months. Other migratory animals (turtles, birds) are also potential vectors.

Radioactivity transport vectors – time scales

Atmosphere	3 days
Biological	4 months
Wind-driven debris	1 y
Current transport	2 y

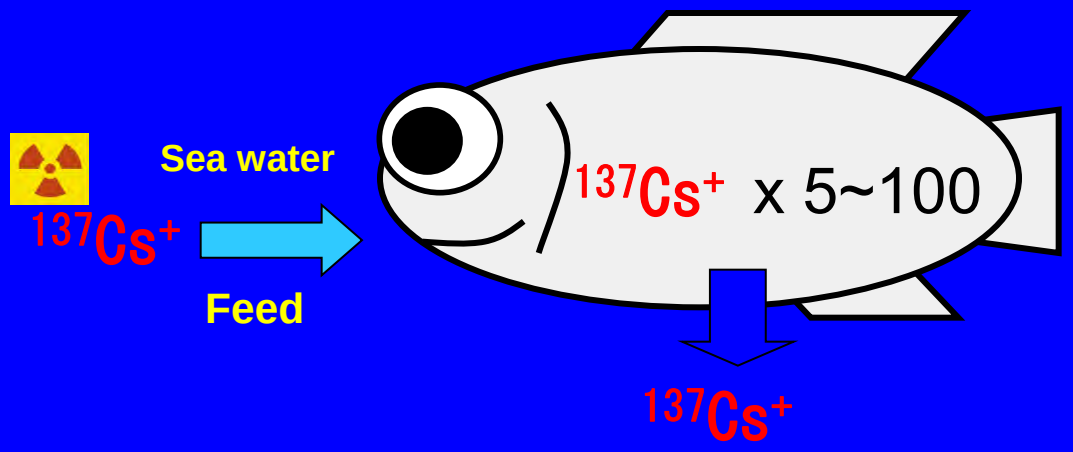
EXPLORE

Tsunami triggers invasion concerns



Gewin V. 2013 Nature 495,13-14

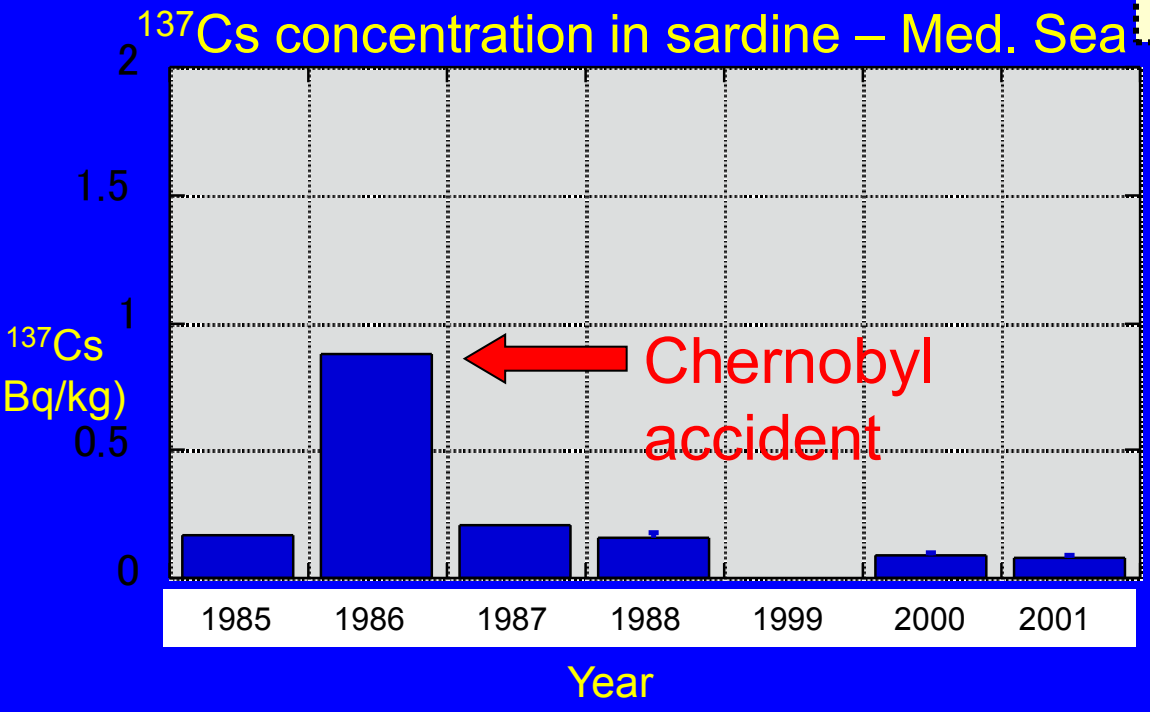
Excretion of radionuclides



Biological half time of

Cs-137＝50 days

Half of Cs-137 is excreted in **50days**. (Lab. results)



^{137}Cs excreted rapidly: no bio-accumulation

Ref: K. Yoshida 、JCAC 34, 1999.
F. Kasamatsu、Radioisotopes 48, 1999.

Biological/sociological Impacts?

FUKUSHIMA INFORM

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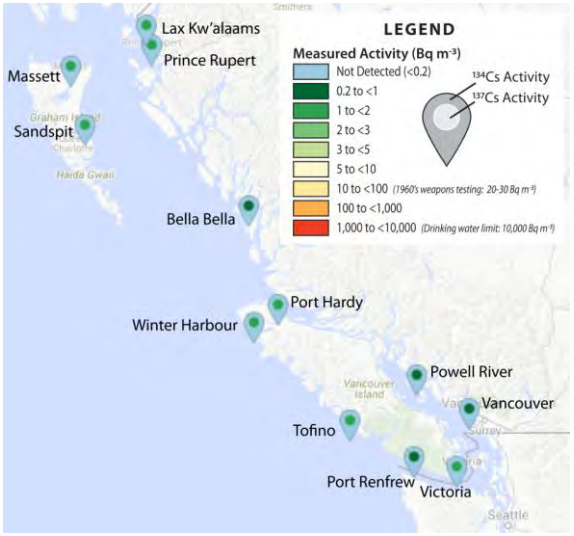
May 2015 e-News v.3

In an effort to communicate results in a timely manner, this e-newsletter reports on the most recent results from the InFORM monitoring network along the coast of British Columbia. In addition to the offshore seawater sampling program and monitoring of marine organisms in collaboration with partners at Fisheries and Oceans Canada and Health Canada, we are collecting coastal seawater samples from fourteen communities along the BC coast. Each sample is collected by a citizen scientist and processed and analyzed by the Fukushima InFORM team at the University of Victoria and their partners across Canada and the US.



InFORM newsletter

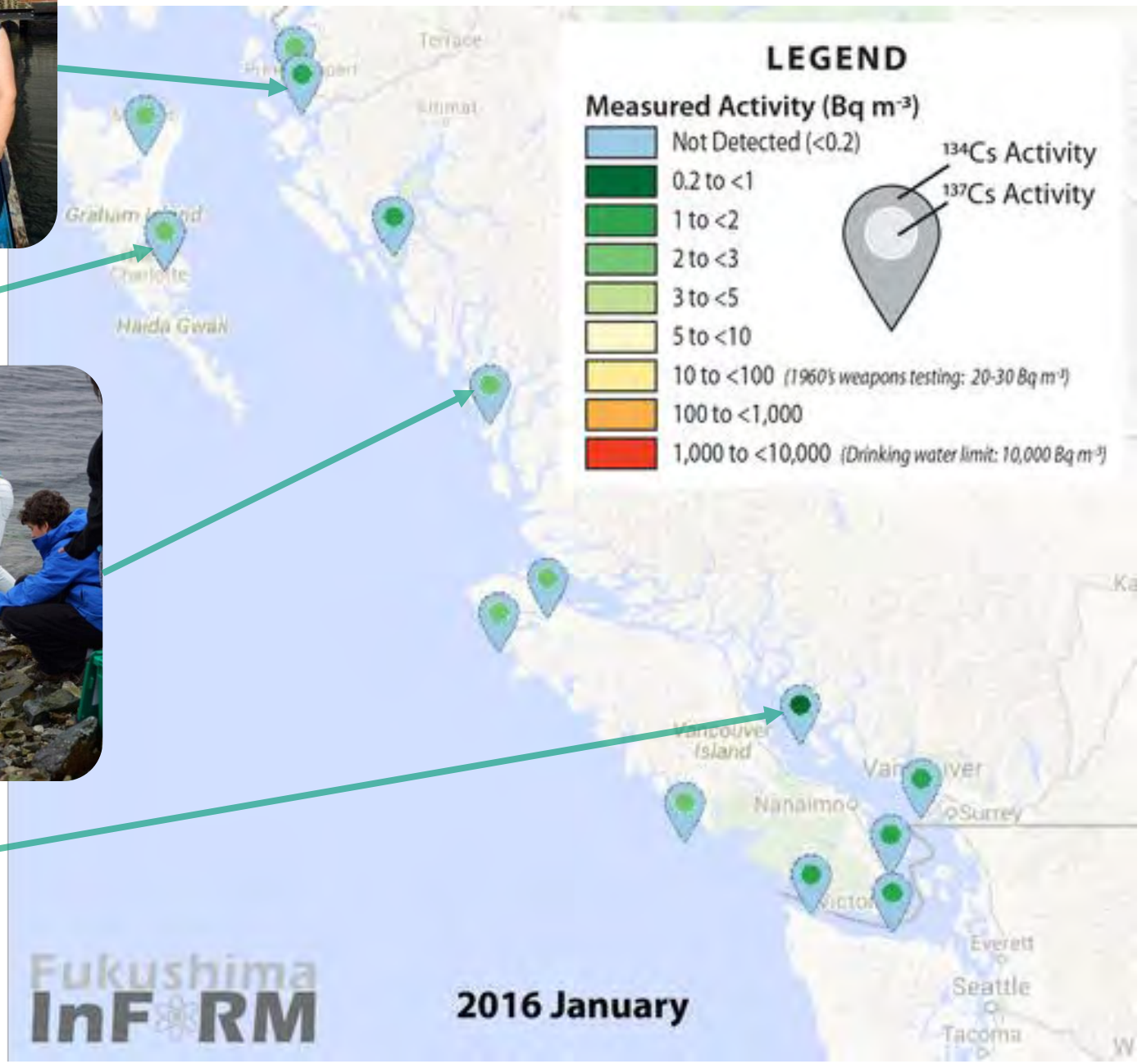
Canadian Fukushima Monitoring Program

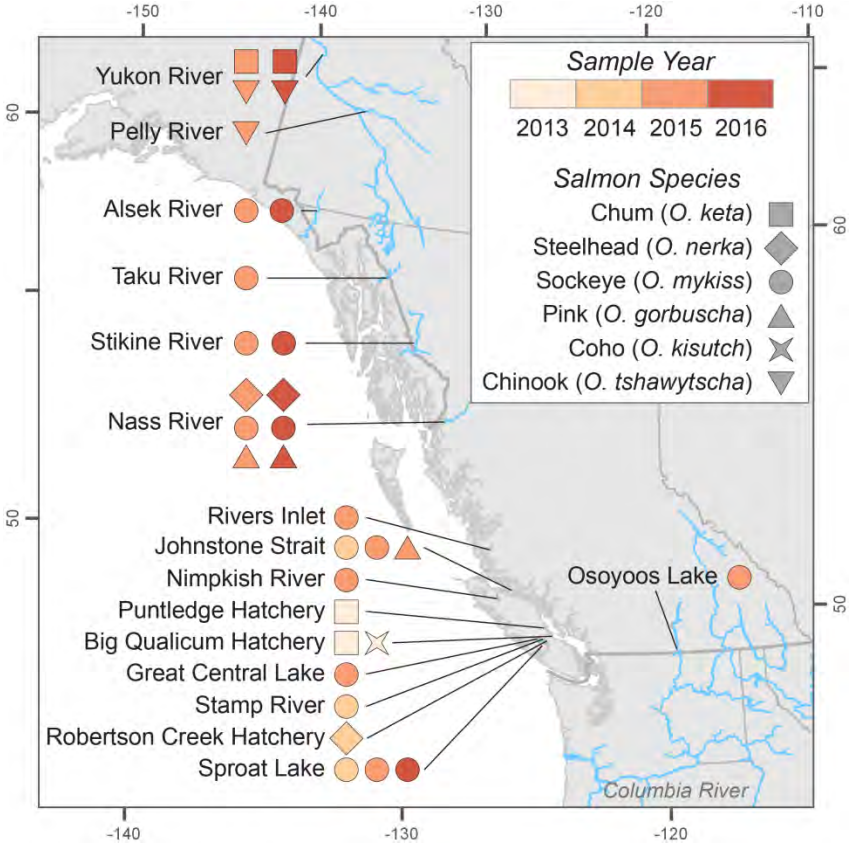
InFORM

MEOPAR Sponsor

Collaboration:
Government (DFO; HC)
Universities (UVic, UBC, UOtt.
International (WHOI)

Offshore Monitoring (DFO)
Coastal Monitoring (citizen scientists)


LEGEND
Measured Activity (Bq m⁻³)
Not Detected (<0.2)
0.2 to <1
1 to <2
2 to <3
3 to <5
5 to <10
10 to <100 (1960's weapons testing: 20-30 Bq m⁻³)
100 to <1,000
1,000 to <10,000 (Drinking water limit: 10,000 Bq m⁻³)
¹³⁴Cs Activity
¹³⁷Cs Activity
Terrace
Kitimat
Graham Island
Charlotte
Haida Gwaii
Vancouver Island
Nanaimo
Surrey
Everett
Seattle
Tacoma
Fukushima
InFORM
2016 January



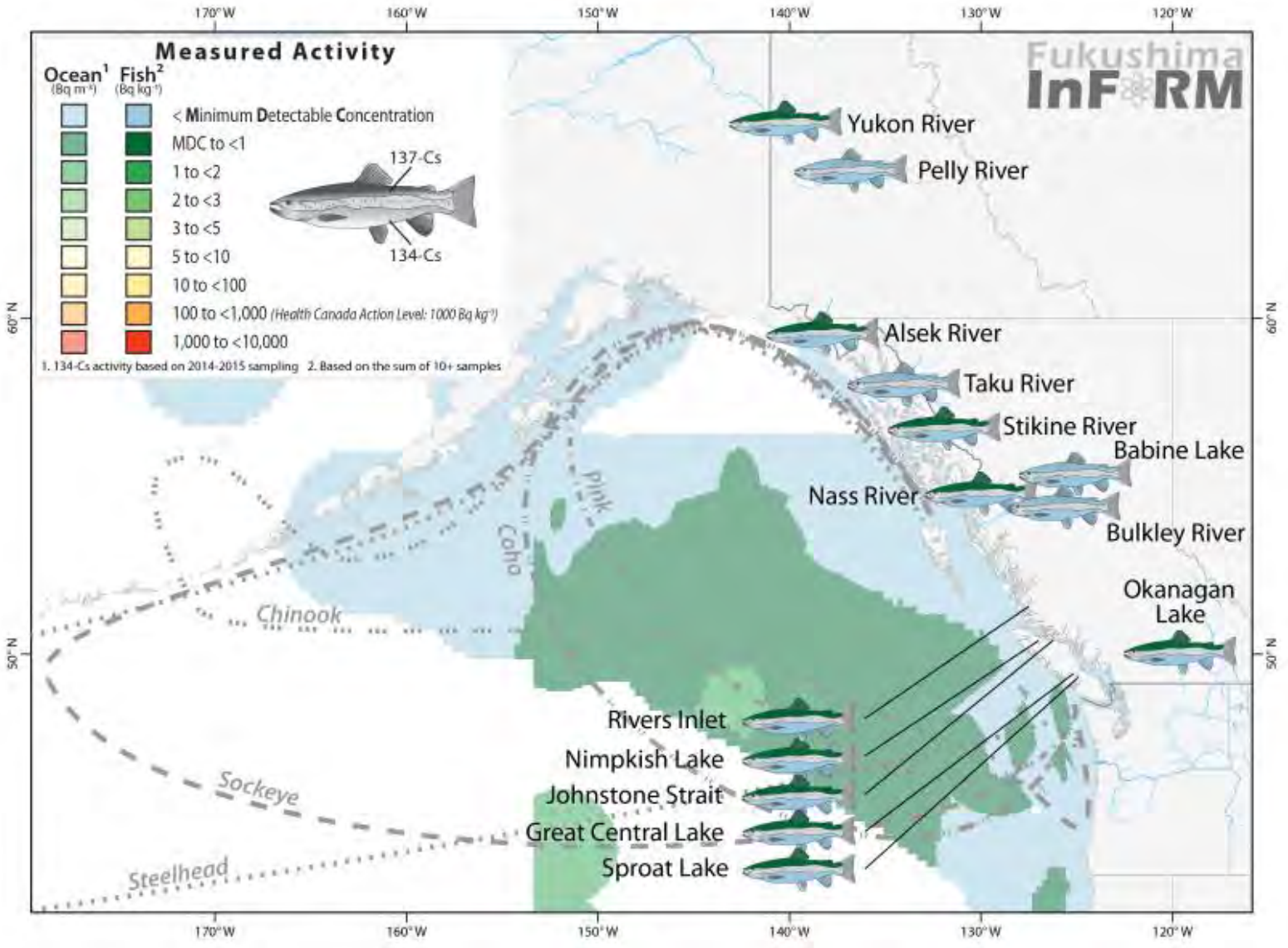
Map of salmon samples collected from 2013 to 2016 during upstream migration.

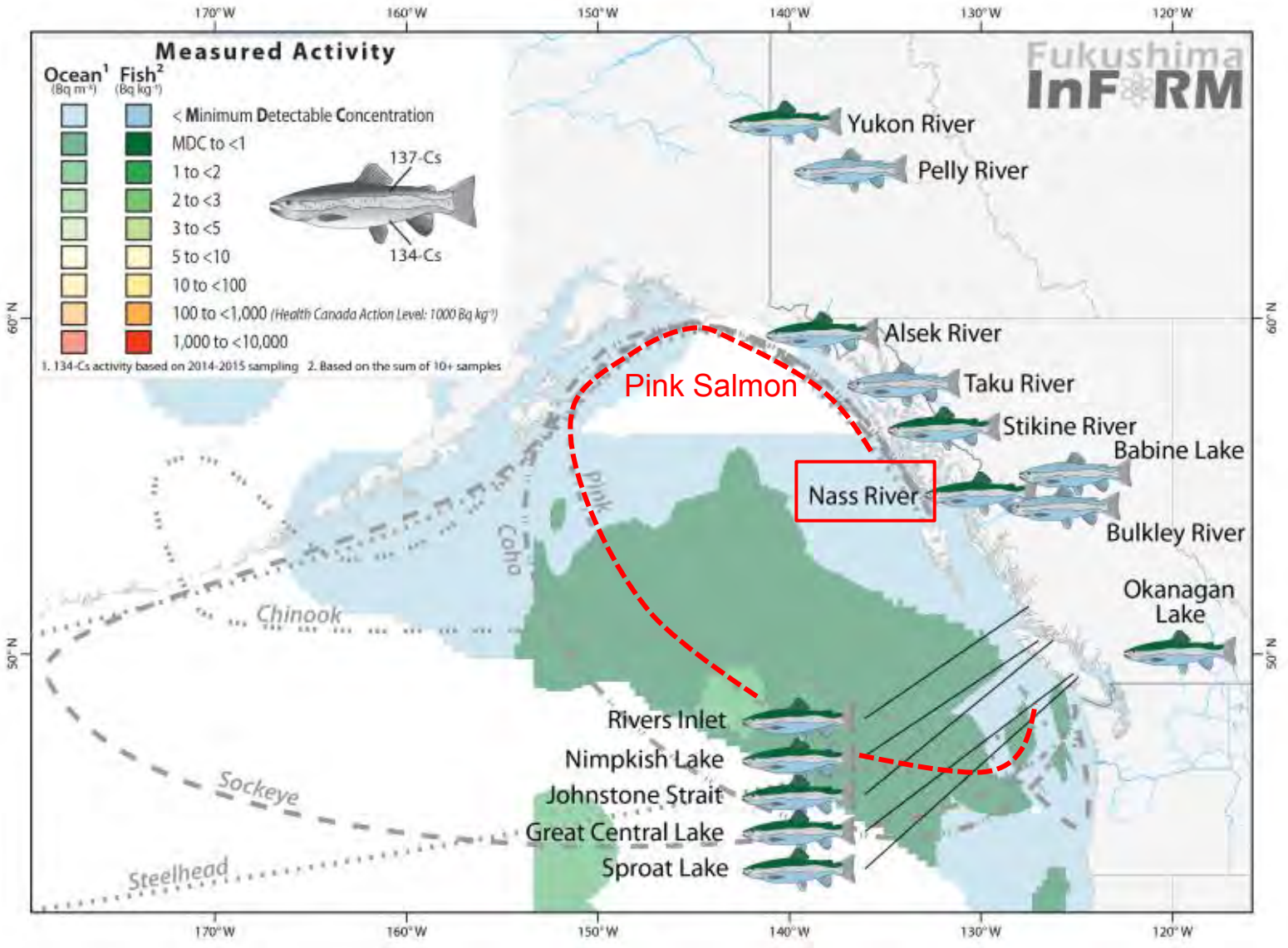
Salmon Results Summary

Year	# Samples	# with ^{137}Cs	Avg ^{137}Cs (Bq/kg) dry wt
2014	89	0	0.21
2015	156	7	0.18
2016	123	9	0.19

Species	Origin	^{137}Cs (Bq/kg)	+/-	^{134}Cs (Bq/kg)	+/-
Sockeye Salmon	Stikine Riv., B.C.	1.01	0.08	n.d.	
Sockeye Salmon	Alsek River, B.C.	0.83	0.07	n.d.	
Steelhead Trout	Nass River, B.C.	0.78	0.06	n.d.	
Steelhead Trout	Nass River, B.C.	1.61	0.10	n.d.	
Sockeye Salmon	Rivers Inlet, B.C.	0.94	0.06	n.d.	
Pink Salmon	Nass River, B.C.	1.78	0.11	n.d.	
Pink Salmon	Nass River, B.C.	1.31	0.09	n.d.	
Pink Salmon	**Nass River, B.C.**	**2.35**	**0.14**	**0.31**	**0.05**
Sockeye Salmon	Sproat Lake, B.C.	1.11	0.08	n.d.	

^{134}Cs (unequivocably from Fukushima) measured in one salmon in Nass River, B.C. in 2015 and again in 2016, enough to trigger a small media sensation.


Measured Activity
Ocean¹ (Bq m⁻³)
Fish² (Bq kg⁻¹)
< Minimum Detectable Concentration
MDC to <1
1 to <2
2 to <3
3 to <5
5 to <10
10 to <100
100 to <1,000 (Health Canada Action Level: 1000 Bq kg⁻¹)
1,000 to <10,000
137-Cs
134-Cs
1. 134-Cs activity based on 2014-2015 sampling 2. Based on the sum of 10+ samples
Fukushima InFORM
Yukon River
Pelly River
Alsek River
Taku River
Stikine River
Babine Lake
Nass River
Bulkley River
Okanagan Lake
Rivers Inlet
Nimpkish Lake
Johnstone Strait
Great Central Lake
Sproat Lake
Pink
Coho
Chinook
Sockeye
Steelhead
170° W
160° W
150° W
140° W
130° W
120° W
60° N
50° N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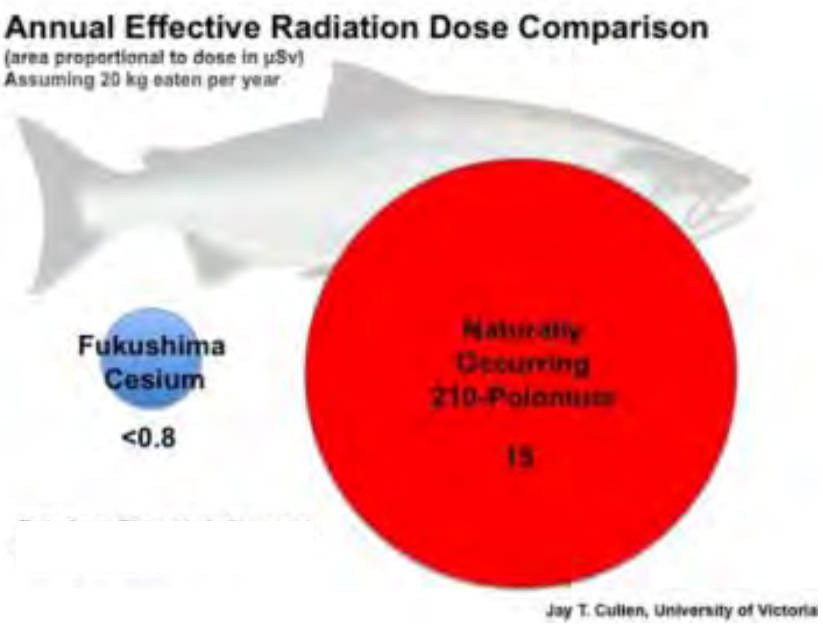

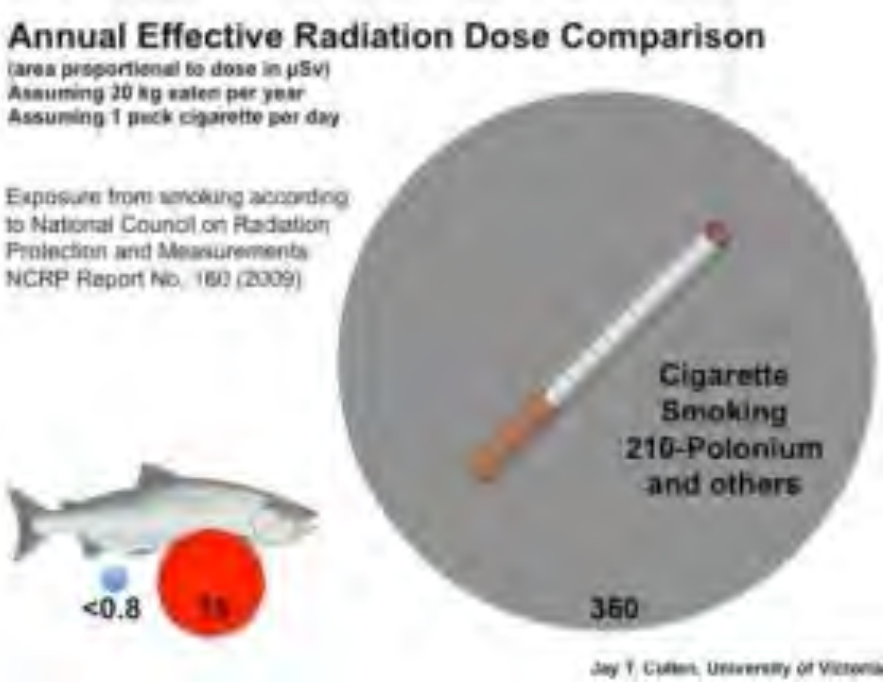

Radiation dose from fish consumption is much greater from natural ^{210}Po compared to ^{137}Cs.

Radiation dose from smoking order of magnitude greater than from seafood consumption.

Fukushima Monitoring Summary

1. By Feb. 2017, levels of ^{137}Cs were still increasing over the shelf, but had begun to decline in the interior of the subpolar gyre: tracer signal observed in Bering Sea and probably entering the Arctic Ocean.

2. Surface water distribution of Fukushima signal was congruent with that of warm temperature anomaly “the Blob” which was governed by ridge of high atmospheric pressure that persisted over NE Pacific coast through 2014.

3. Good agreement (generally) between Line P results and Rossi model: discrepancies traced to erroneous input function in Rossi model.

4. DFO Monitoring program led to InFORM: citizen oriented coastal/ biological monitoring with robust public outreach that has effectively “informed” and educated public about Fukushima radiological threats.

Thank you for your attention!