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San Diego, March 12-16, 2018

Pathways, impacts and fate of marine debris generated by the 2011 tsunami in Japan derived from a synthesis of numerical models and observational reports

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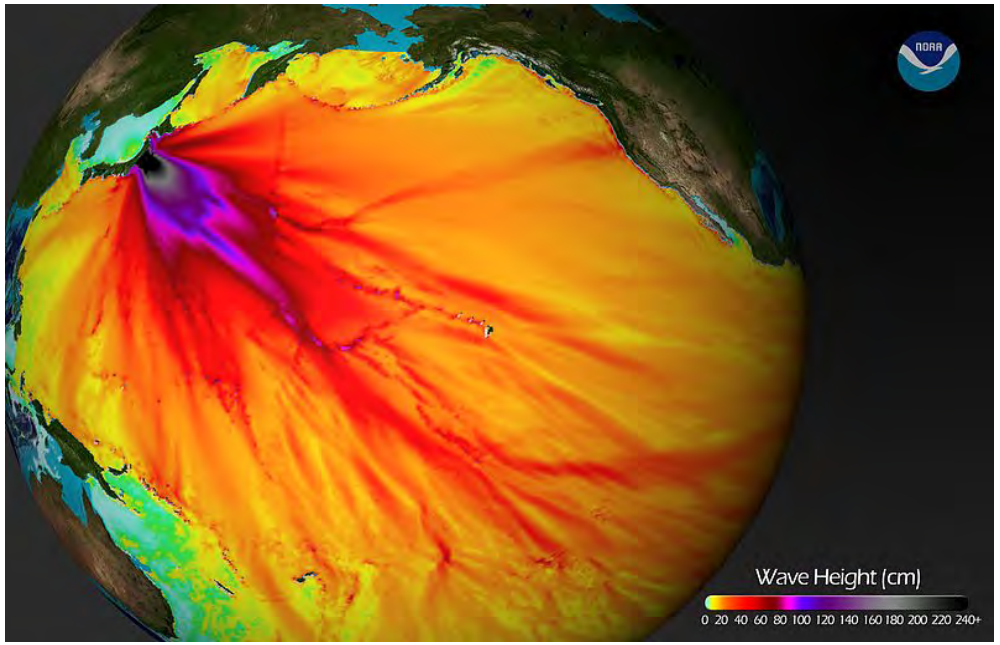
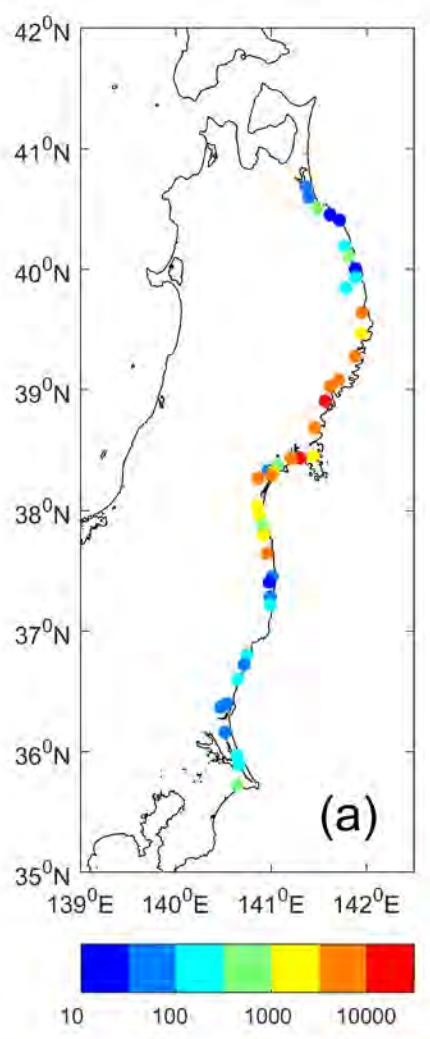
Acknowledgement: PICES ADRIFT Team, NOAA, DLNR and other data teams, numerous volunteers and collaborators

March 11, 2011 Tsunami in Japan

- > 15 thousand victims
- > 100,000 home destroyed

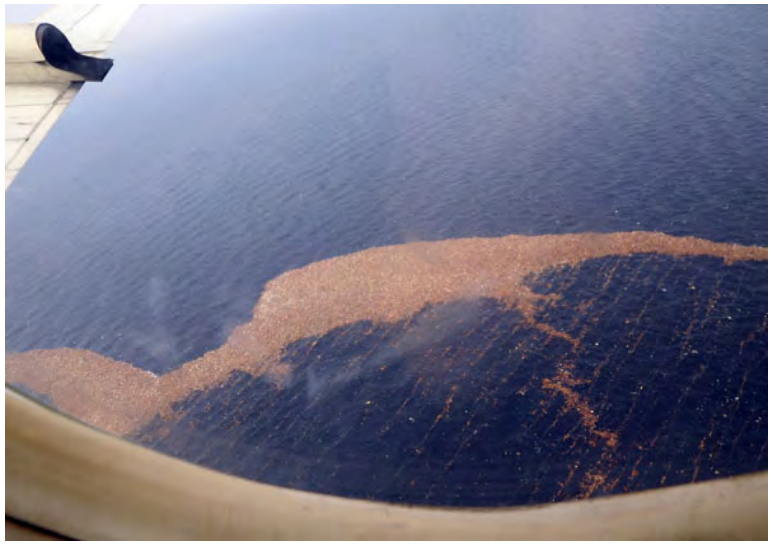




> 1.5 million tons of floating debris generated – i.e., equivalent of a full year North Pacific budget of general debris

Due to many identifiable items and nearly instantaneous release tragic tsunami of March 11, 2011 provided unique data on marine debris drift.

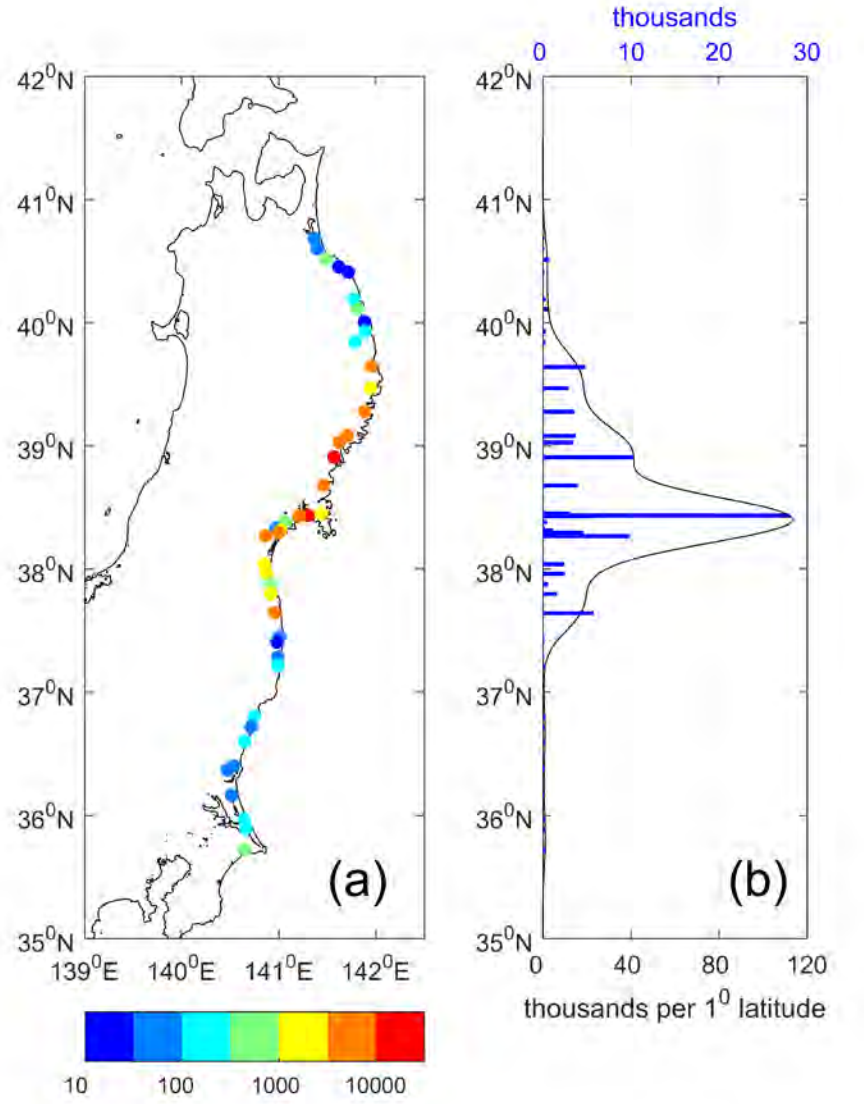
Massive amount of debris generated



Courtesy of US Navy

Generation of this large amount of marine debris in a single event was unprecedented event in modern history. Many objects traveled across the North Pacific and were found in remote areas.

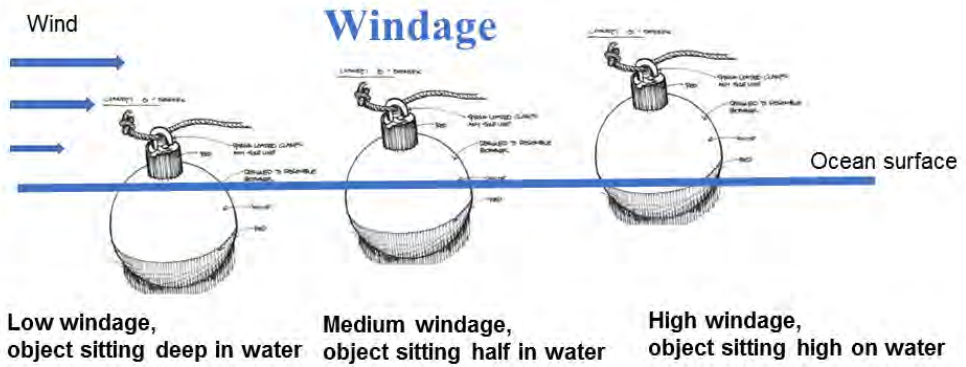
Source distribution for model experiments



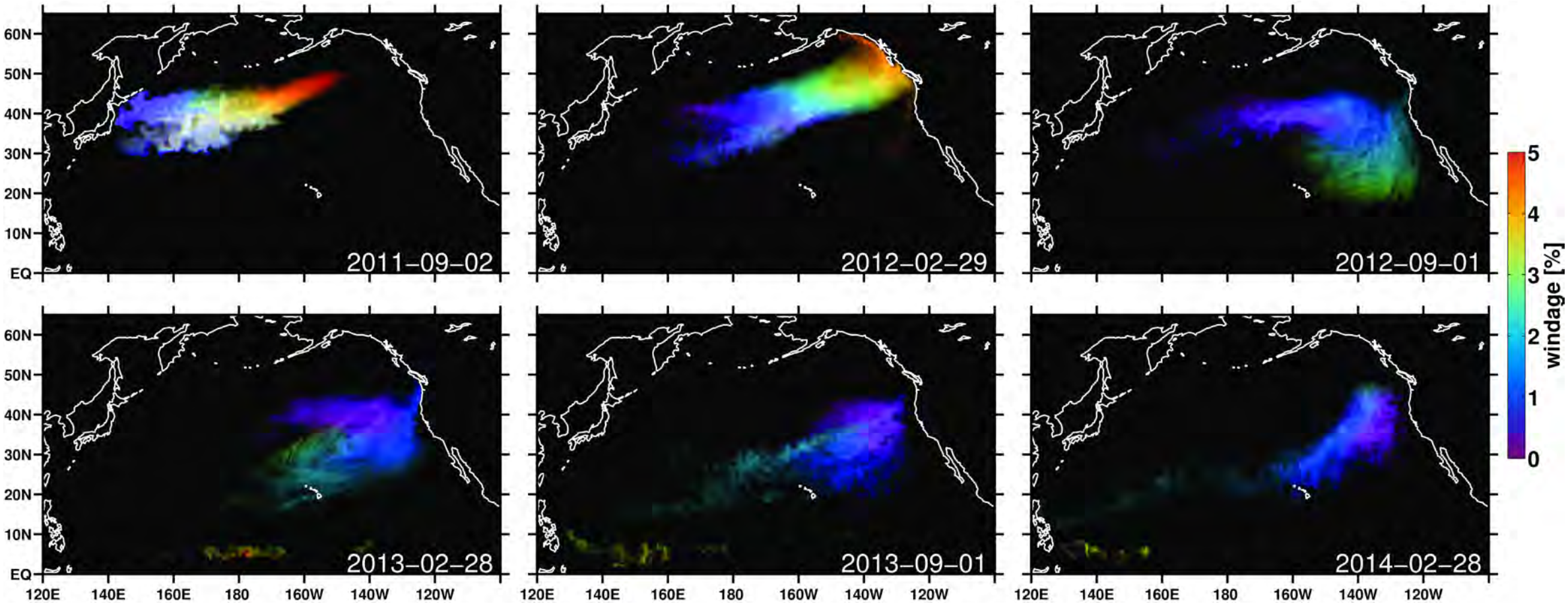
5 numerical models were used in this study:

- GNOME system, used by NOAA for oil spills. It calculates particle trajectories, using HYCOM currents and NOAA Blended Sea Winds. 400,000 particles deployed for each windage.
- MOVE/K-7/SEA-GEARN (thereafter, *MOVE*) created by a team of scientists in Japan from JAMSTEC, JAEA, JMA/MRI, and JAXA – 3DVAR from March 2011 to July 2013 followed by the forecast runs through May 2016
- FORA-WNP30 (hereafter, *FORA*) is a 4dVAR ocean re-analysis for the North Pacific over 30 years.
- SCUD – IPRC diagnostic model, using satellite sea level and wind, with coefficients calibrated using trajectories of drifting buoys.
- SCUD blended with HYCOM in coastal areas (SCUD-HYCOM)

Simulations were performed in a broad **windage range: 0% - 6%**



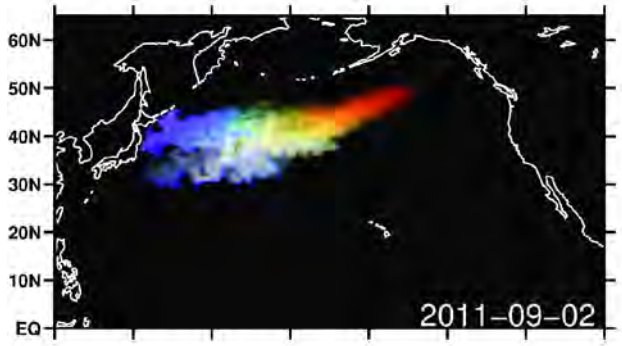
Model simulations of tsunami debris drift



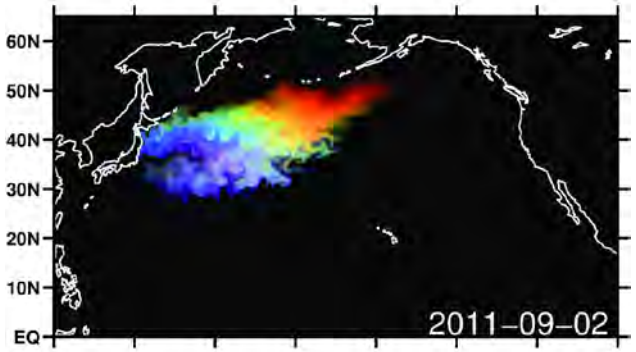
- **Big differences between pathways of different windages suggest that different areas were affected by different types of JTMD and at different times.**

Comparison between models: September 2, 2011

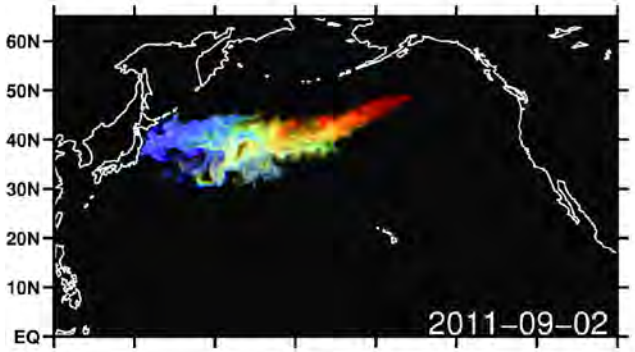
SCUD



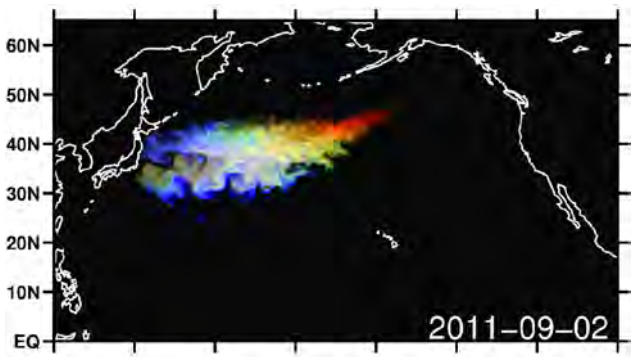
MOVE – 3dVAR



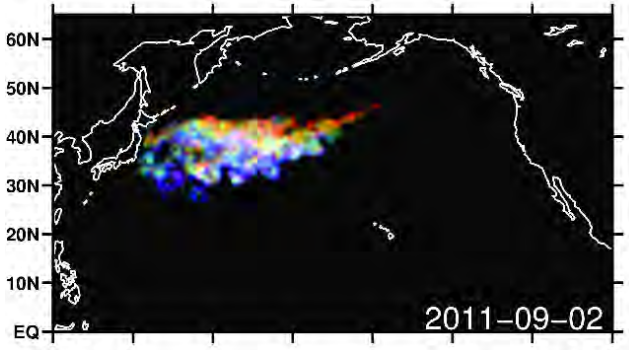
SCUD-HYCOM



FORA – 4dVAR

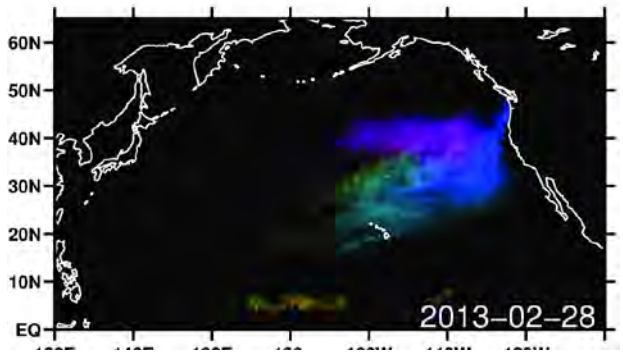


GNOME

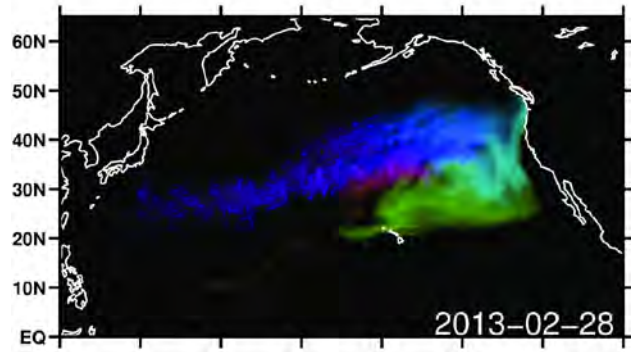


Comparison between models: February 28, 2013

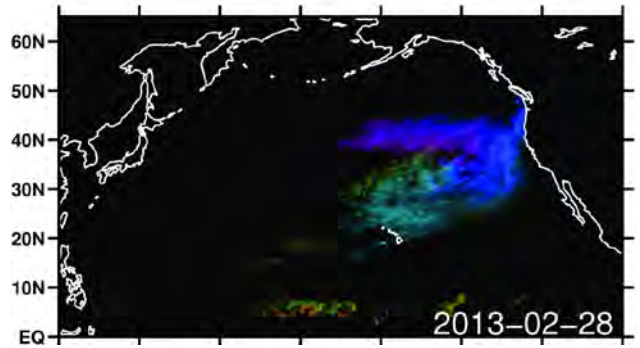
SCUD



MOVE – 3dVAR



SCUD-HYCOM



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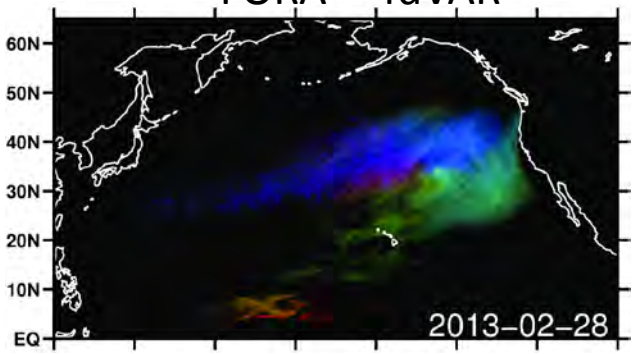
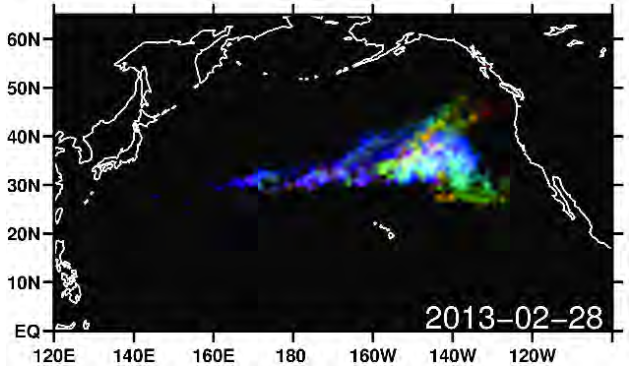
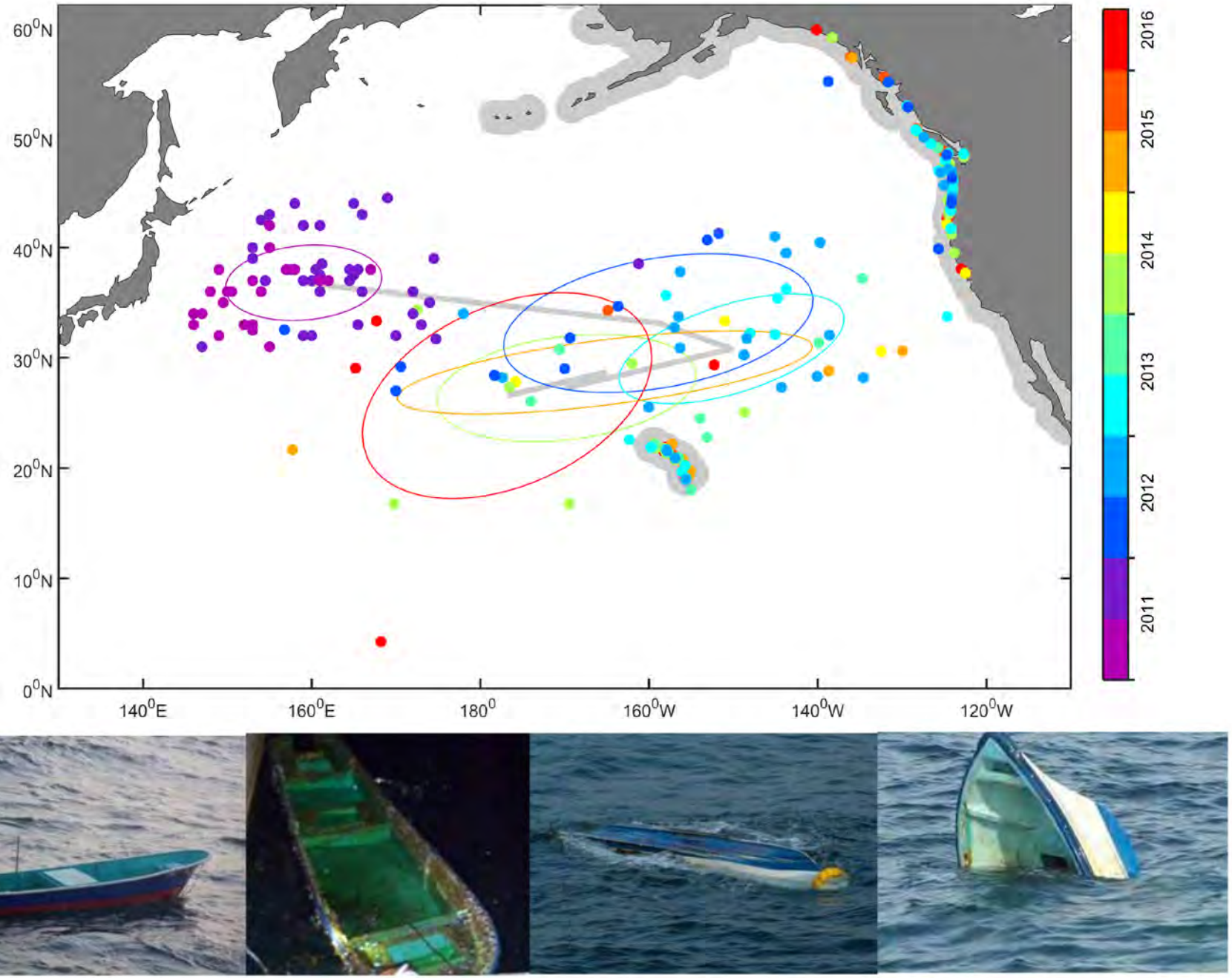


GNOME



Locations (dots) and years (colors) of 327 JTMD boat reports



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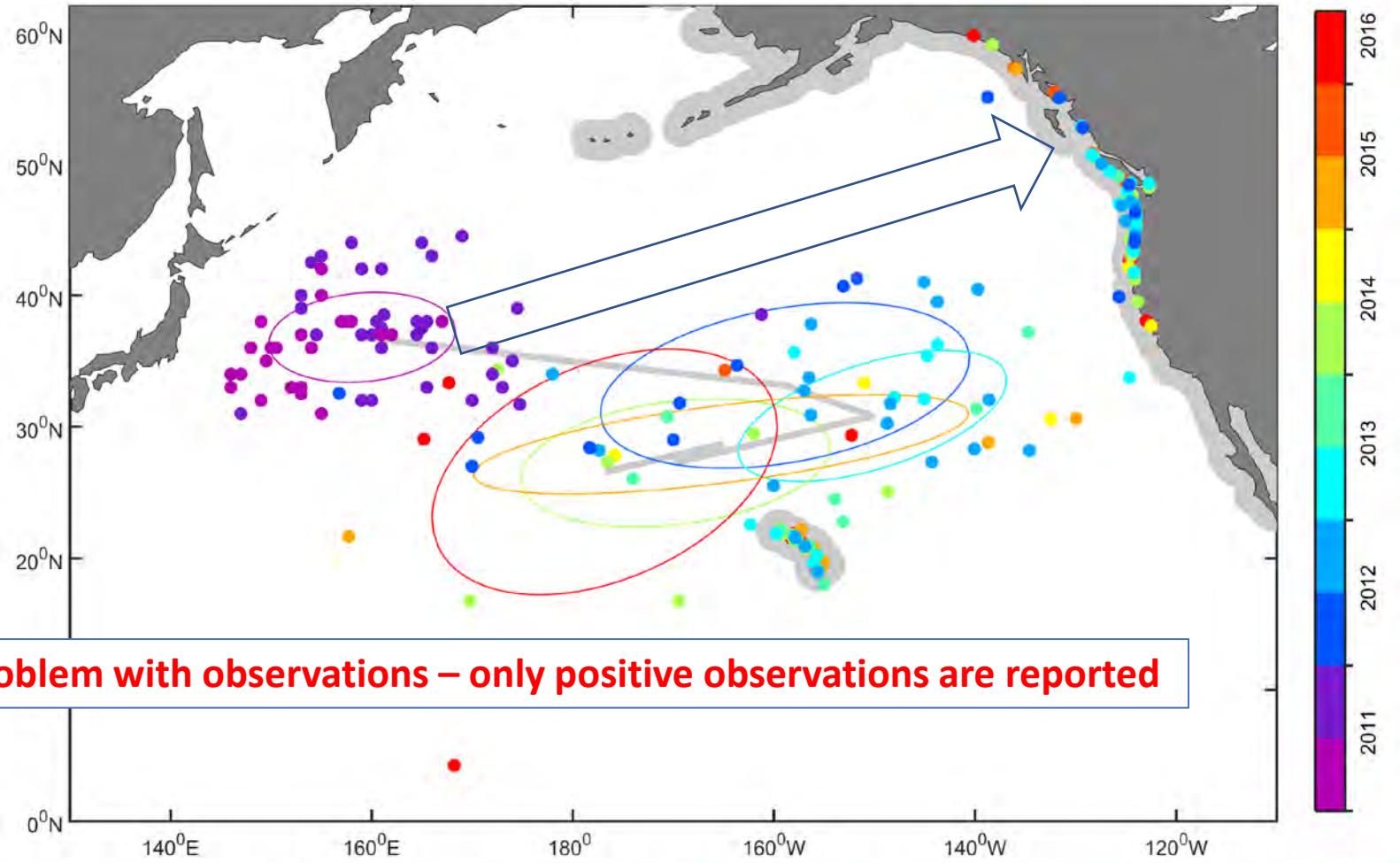
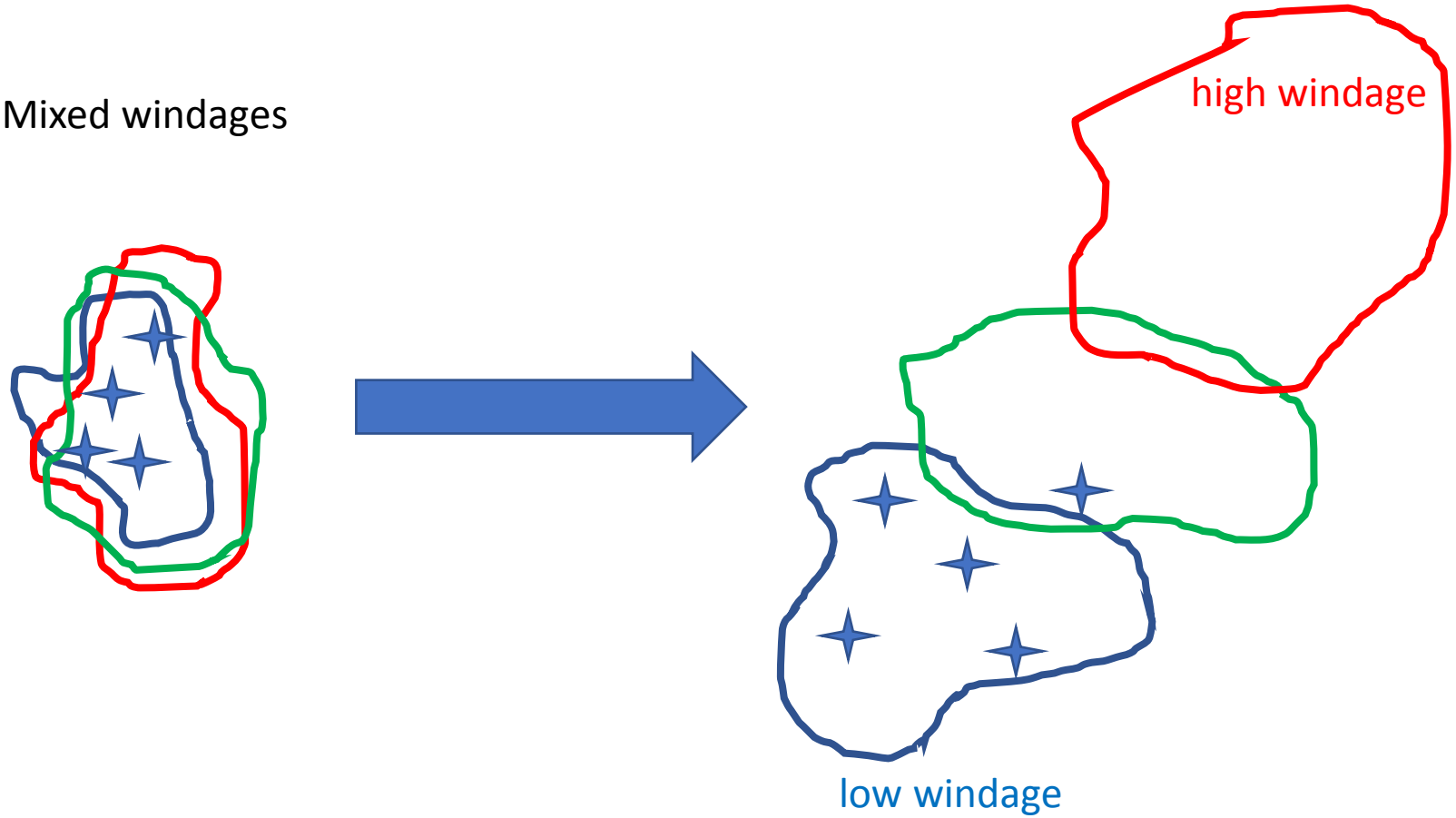


Problem with observations – only positive observations are reported

Stratified windages

Mixed windages



reports from the sea

Determining optimal windage

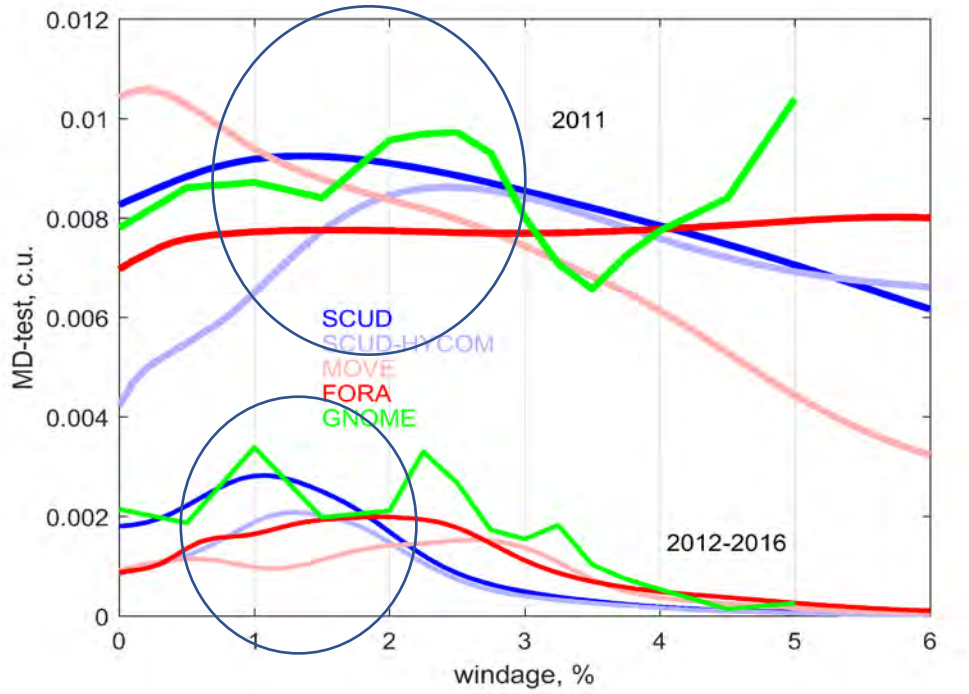
Ideally, to validate model we would compare density of model tracer with observed density of debris, e.g., through:

$\Delta = r.m.s.(C_{model}(x,y,t,windage) - C_{observations}(x,y,t)) \rightarrow min$

and optimal windage would correspond to minimum Δ.

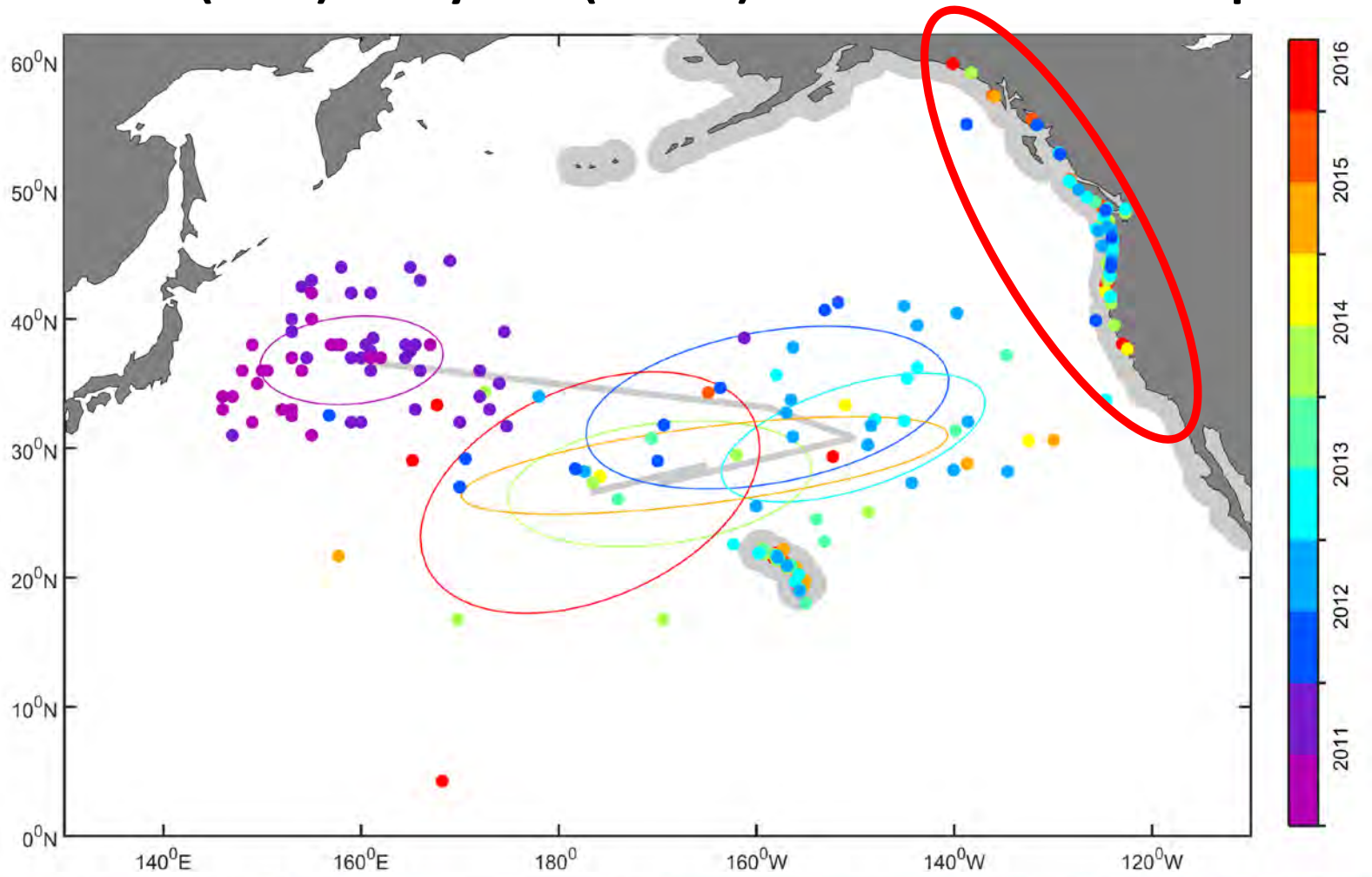
However, if observations are 'independent', success of the model can be estimated integrating model concentration through locations/times of real observations:

$\Delta = SUM(C_{model}(x_{obs},y_{obs},t_{obs},windage)) \rightarrow max$

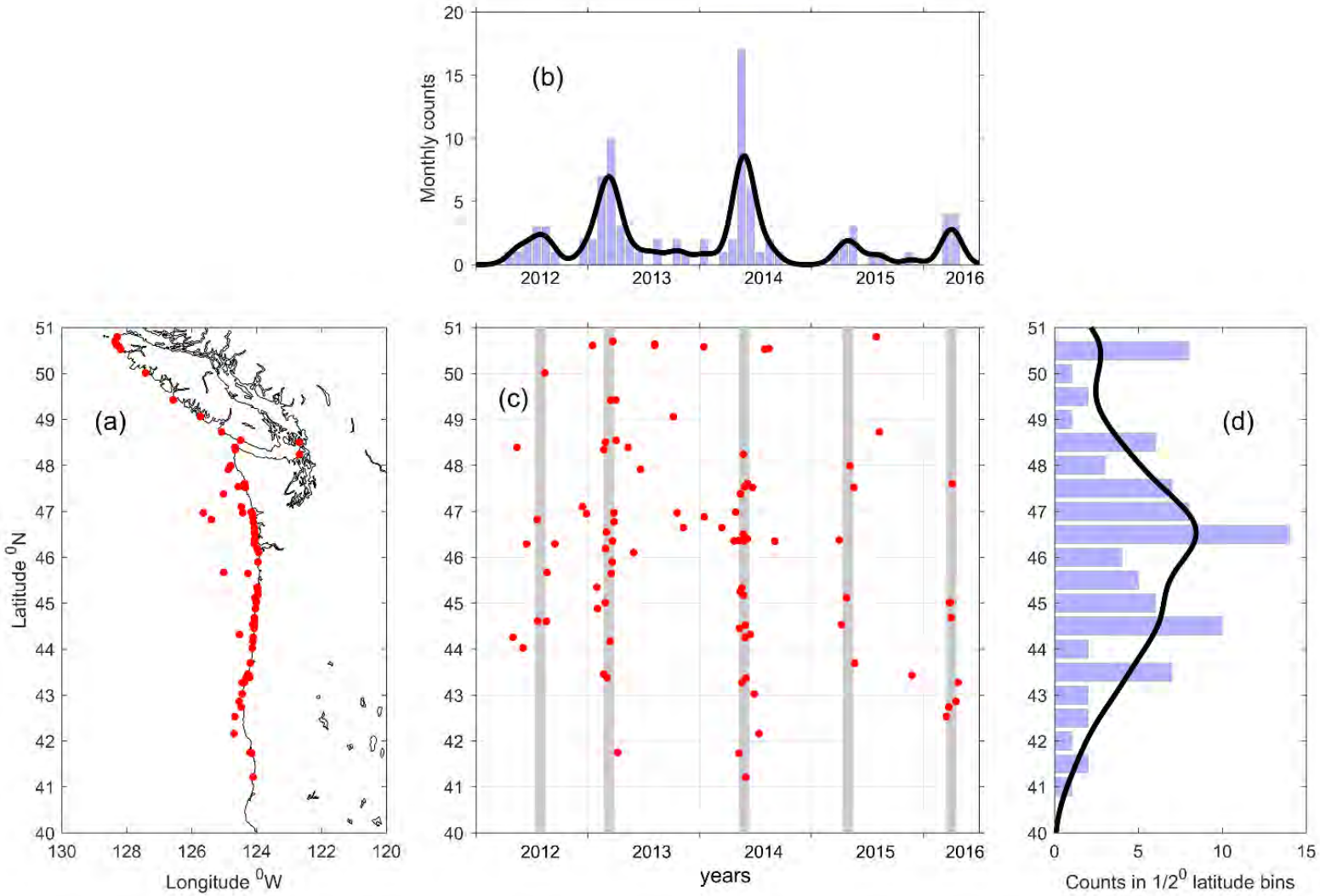


Success of this technique depends on data distribution near the 'debris cloud' edge and quality of the model.
In our case it worked well with the at-sea boat data and SCUD simulations.
Experiments with other models are Underway.

Locations (dots) and years (colors) of 327 JTMD boat reports



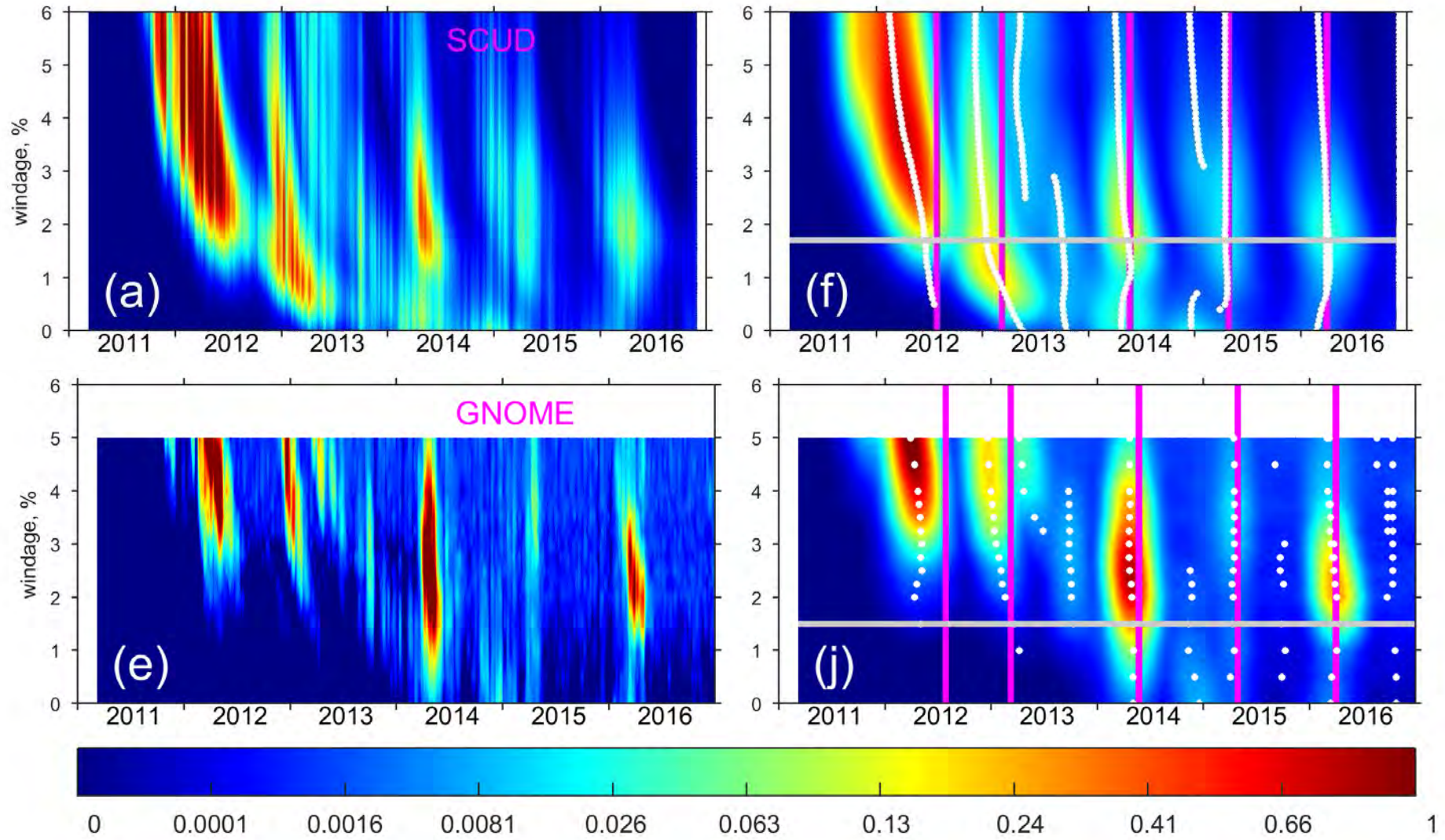
Time-space distribution of 92 boat reports from and near the 40-51ºN stretch of the US/Canada west coast.



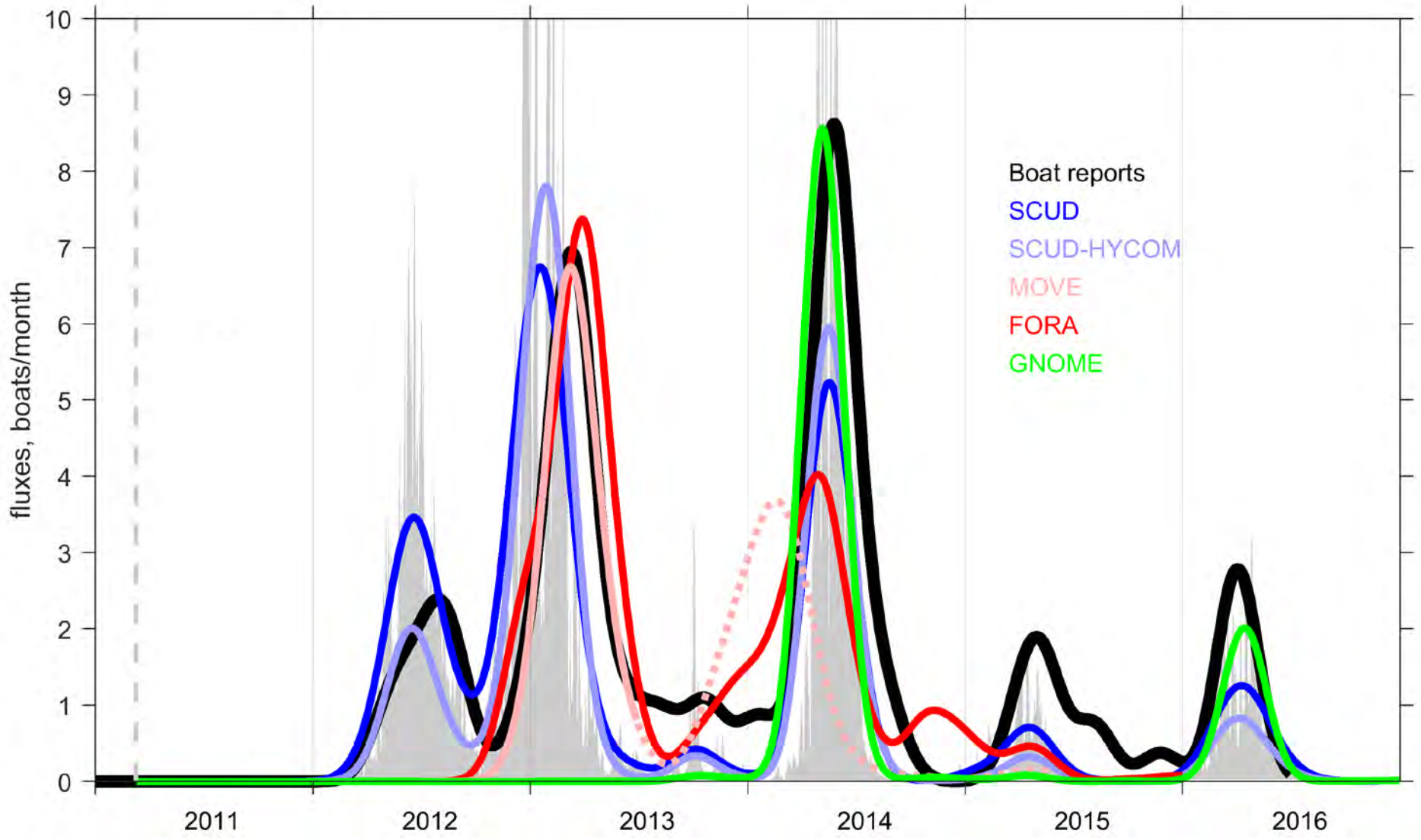
Timelines of model tracer flux on the North American West Coast

SCUD

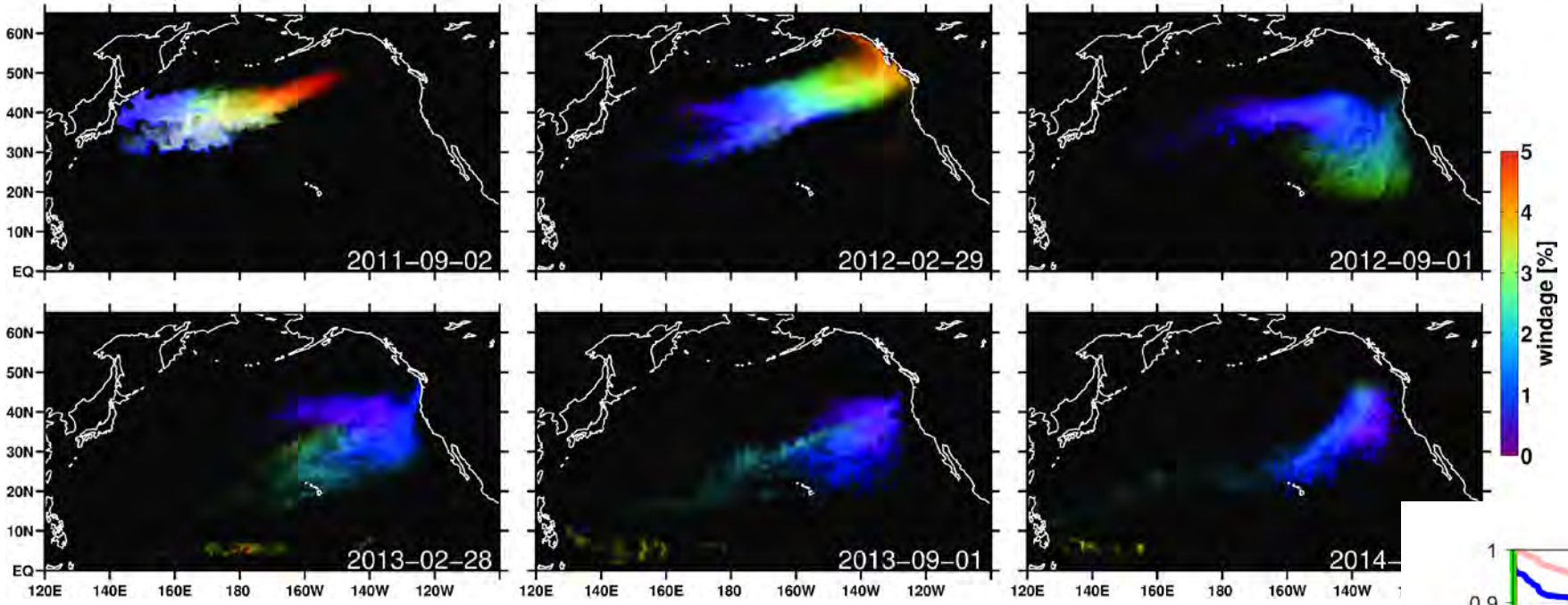
GNOME



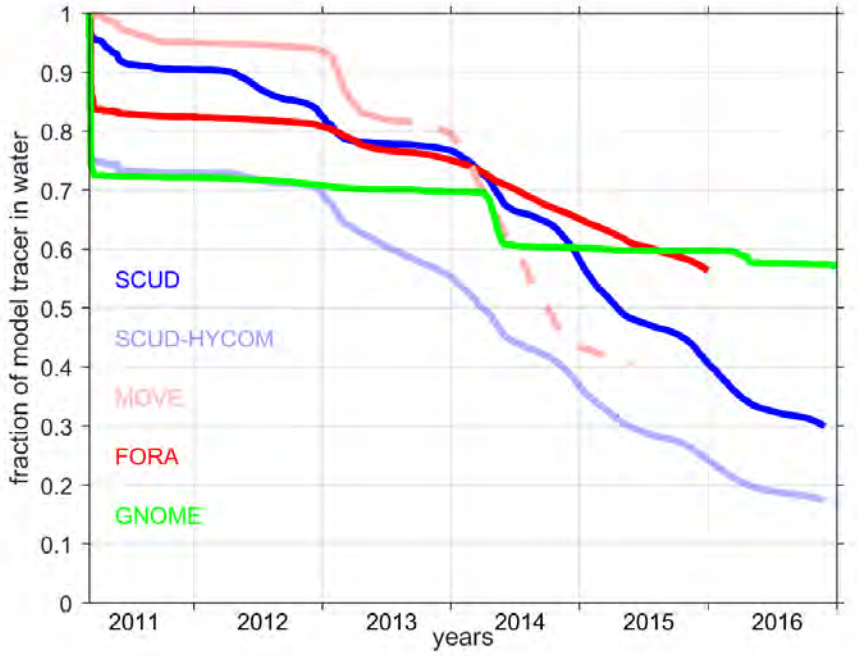
Timelines of boat observations and model solutions for optimal windages



Model simulations of tsunami debris drift

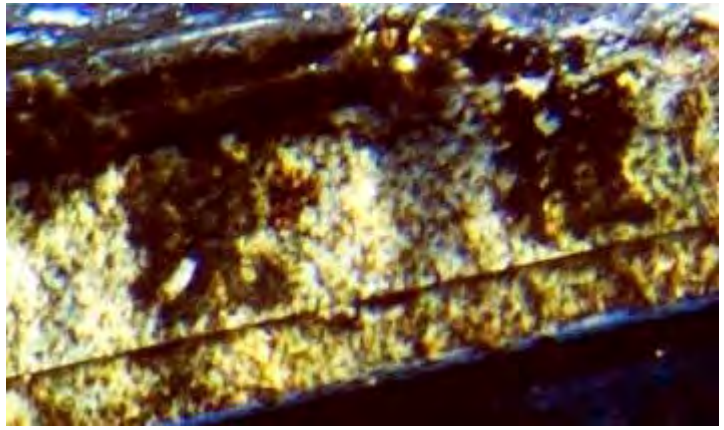


Dissipation timeline of model tracer



- Initial number of boats is estimated ~1000.
- ~ 100 are still floating, most probably, in the garbage patch
- Boats will continue washing ashore in the next several years.

Tsunami boats continue to come, some carry Japanese species



Tsunami boat reported January 22, 2017 off Kona, Island of Hawaii. Credit: Jeffrey Milisen

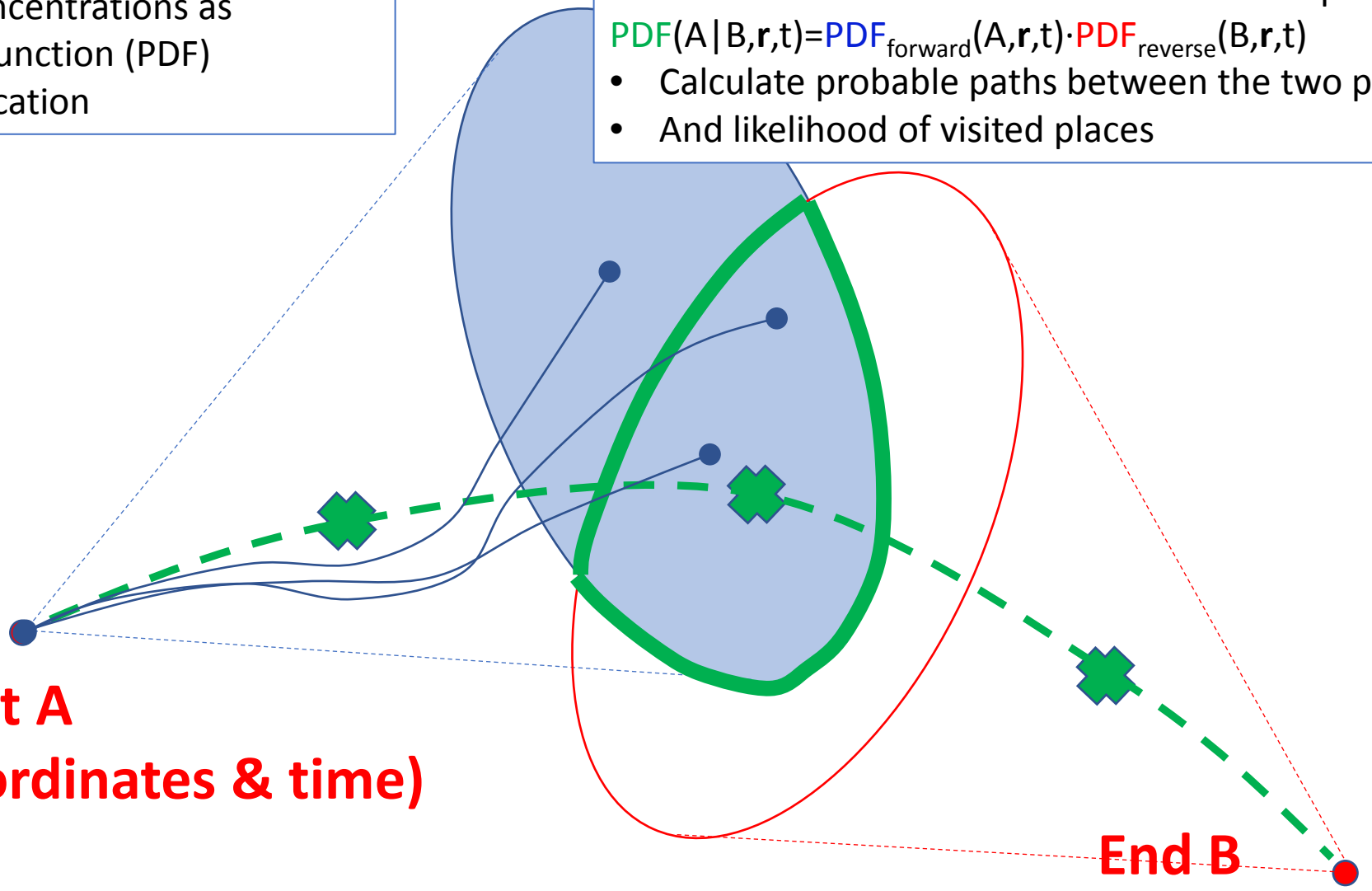
Probabilistic approach to drift simulation

- Interpret tracer concentrations as a probability density function (PDF) for a single-particle location

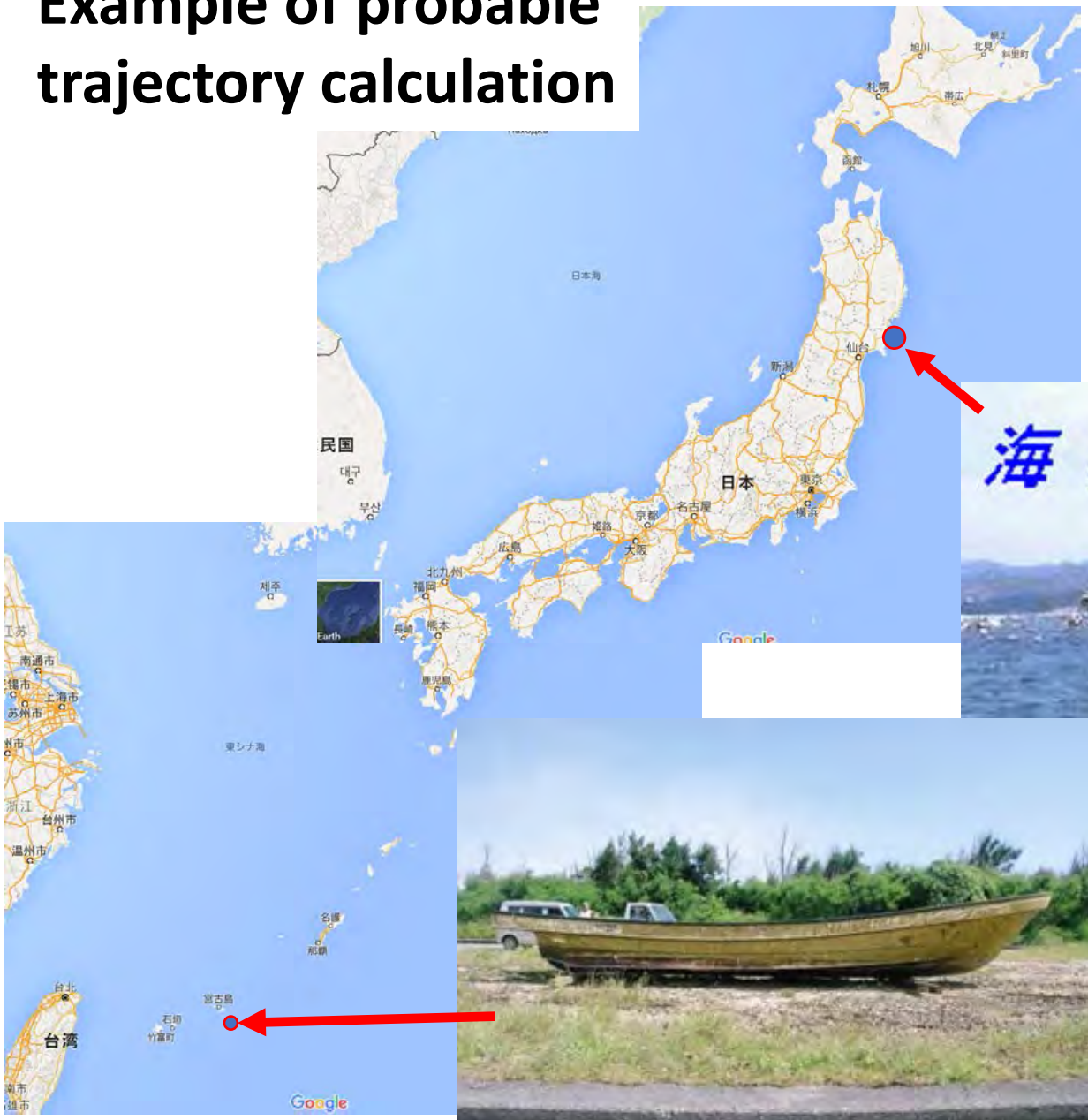
- Estimate reverse pathways (in case when destination is known.
- Combine PDFs with known start and end points:

$PDF(A|B,\mathbf{r},t)=PDF_{forward}(A,\mathbf{r},t)\cdot PDF_{reverse}(B,\mathbf{r},t)$

- Calculate probable paths between the two points
- And likelihood of visited places

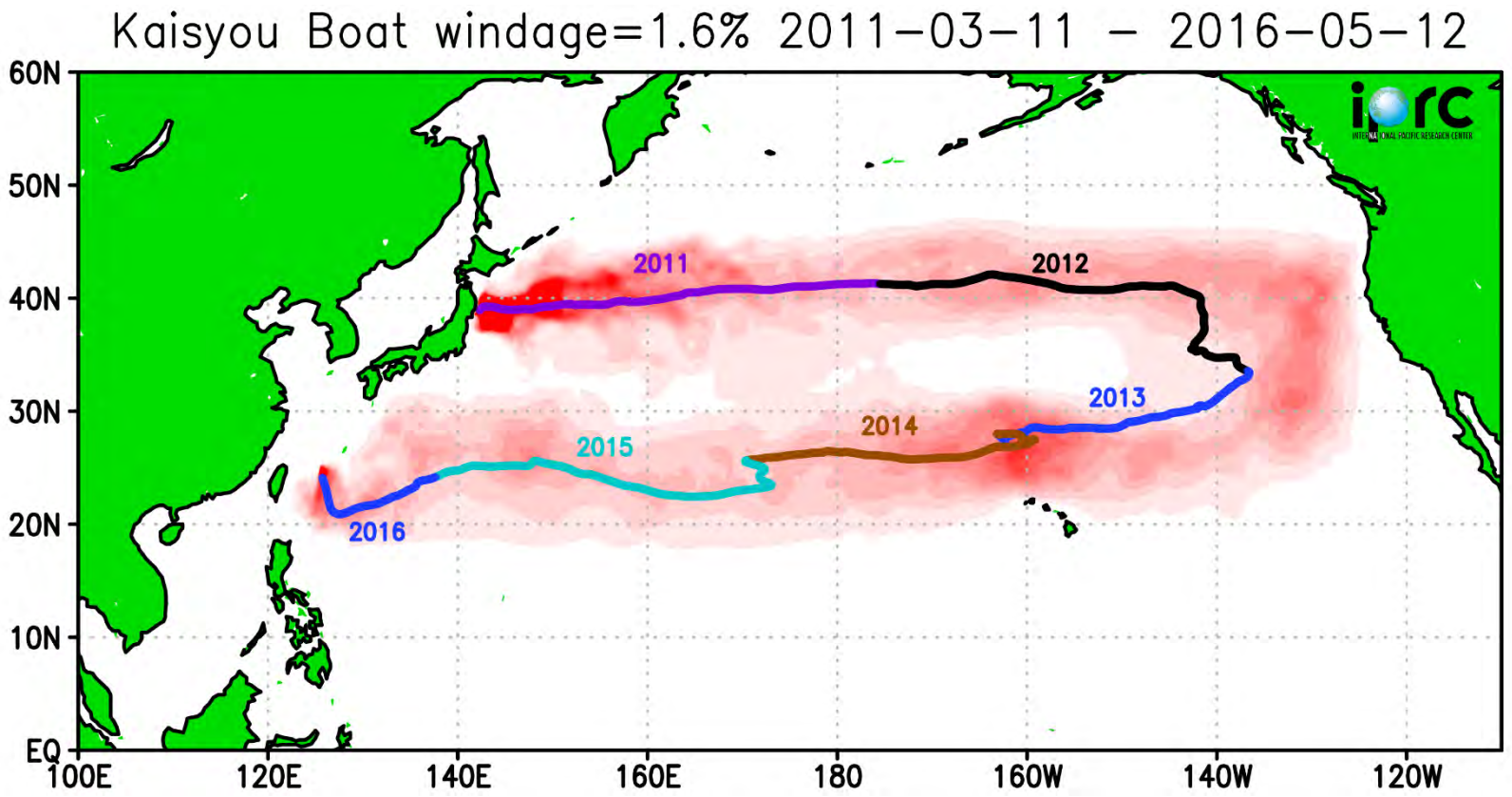


Example of probable trajectory calculation



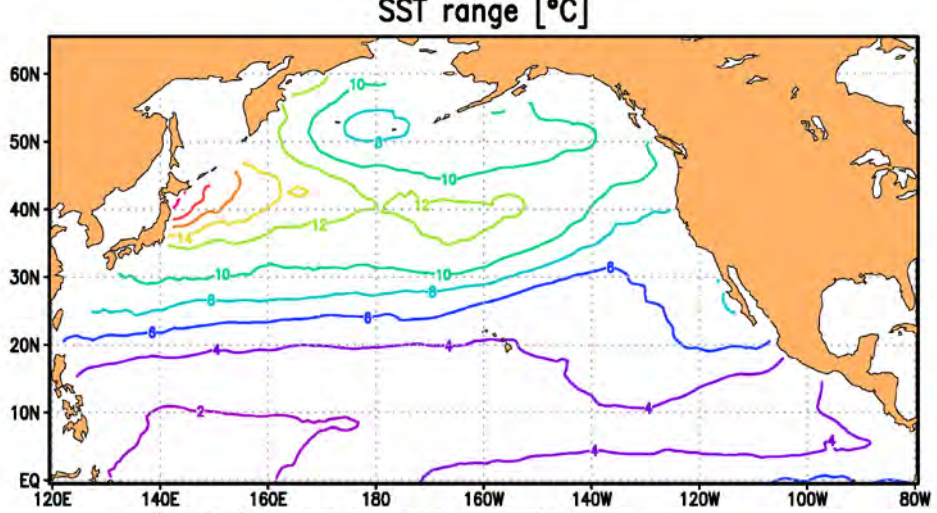
R/V (**Kaisyou**, 1.1ton) of Kesennuma Local Fisheries Laboratory (Miyagi prefecture) was found at about 6km offshore area from Miyako-city, Okinawa prefecture in May 12, 2016.

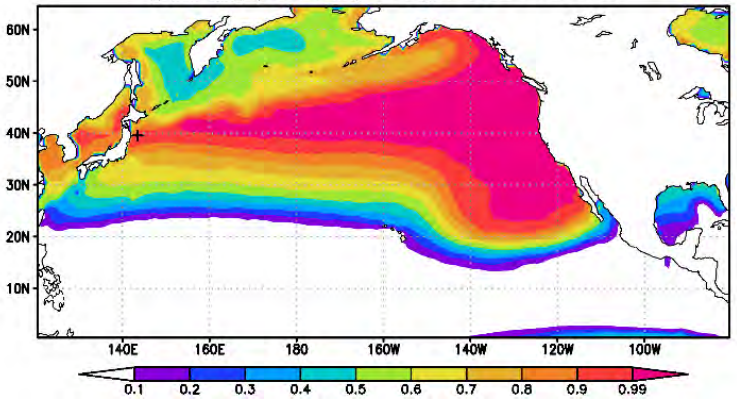
Probable trajectory of R/V Kaisyou



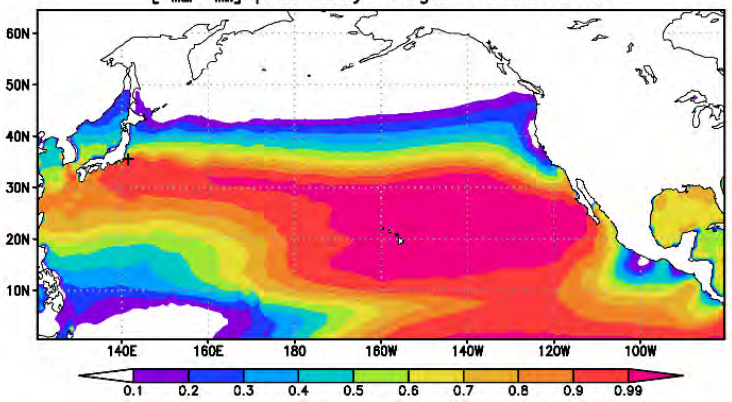
Probable visited locations (colors) and trajectories (lines) for the R/V Kaisyou found May 12, 2016 in Okinawa.

Temperature compatibility along trans- North Pacific drift paths



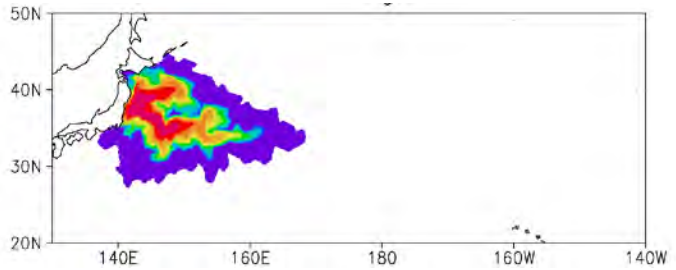


Large range of the SST climatology east of Japan makes possible survival of Japanese coastal species along drift paths leading to the west coast of North America.

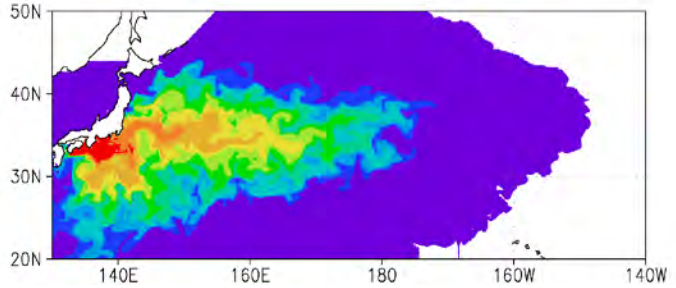


Warm-water species off the southern part of Honshu can survive along the paths, leading to Hawaii.

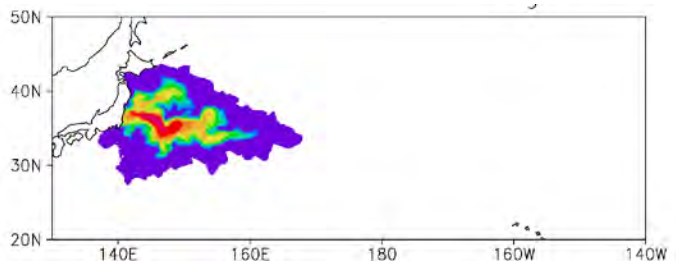
JTMD (2% windage) model – Mar 31, 2011



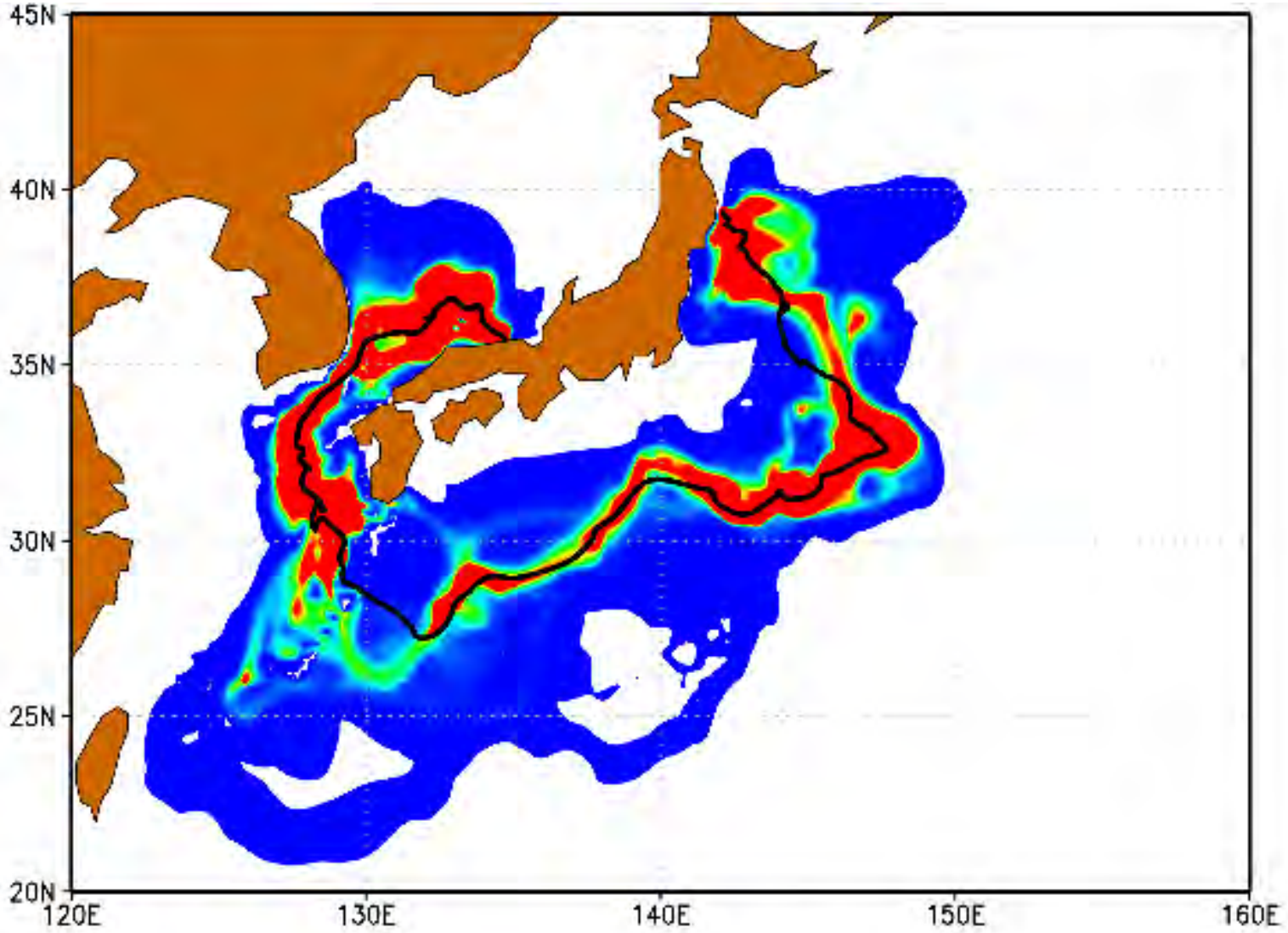
Warm water larvae model – Mar 31, 2011



Interaction between larvae & JTMD



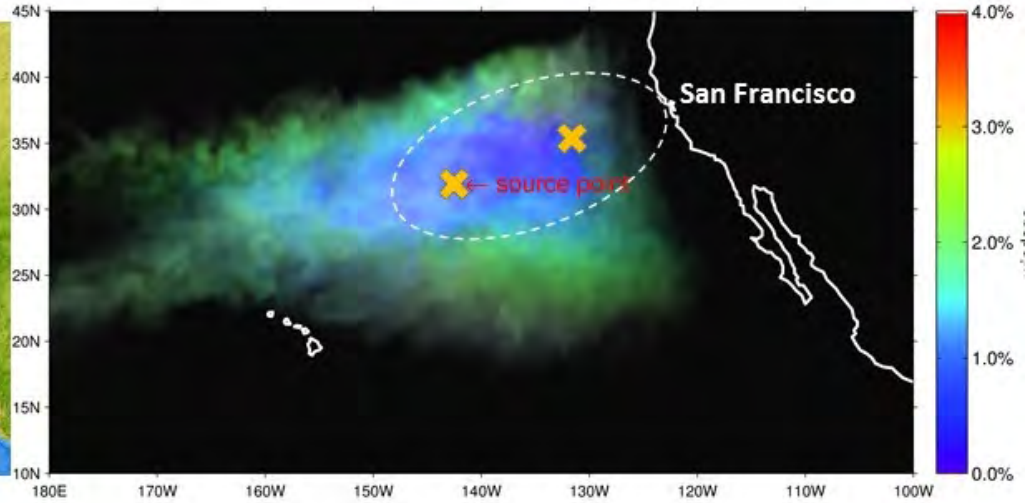
Probable path of tsunami boat found in Kami December 31, 2011 suggests that JTMD could cross the Kuroshio Extension and get in contact with warm-water species.

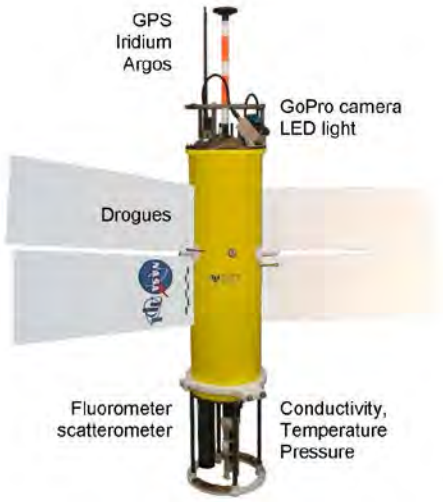


Warm-water Japanese coastal species were found on JTMD in North America and Hawaii. *Carlton et al.*

New project: Physical and biological processes maintaining a unique floating ecosystem of the North Pacific garbage patch

In partnership with Smithsonian Institution, Scripps Institution of Oceanography, Applied Physics Laboratory, and Ocean Voyages Institute

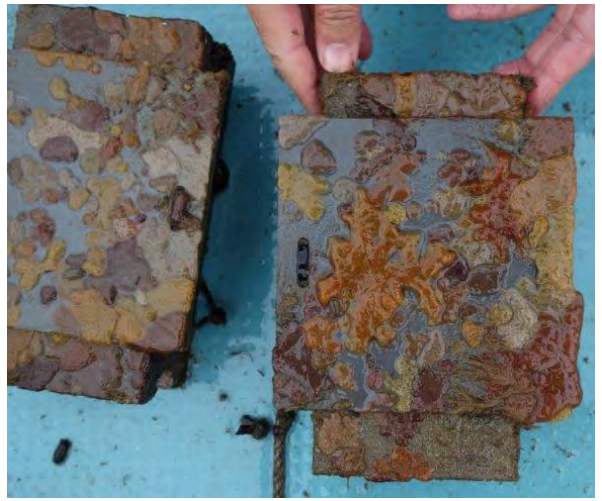




The project will deploy sets of oceanographic instruments to study the hydrodynamics of various types of marine debris and collect biological samples in search for coastal species on debris floating in the garbage patch.

We are looking for at-sea partnership!

Please contact us if you have field work plans in the Northeastern Pacific in 2018-2010.



THANK YOU!