Modeling the drift of marine debris generated by the 2011 tsunami in Japan

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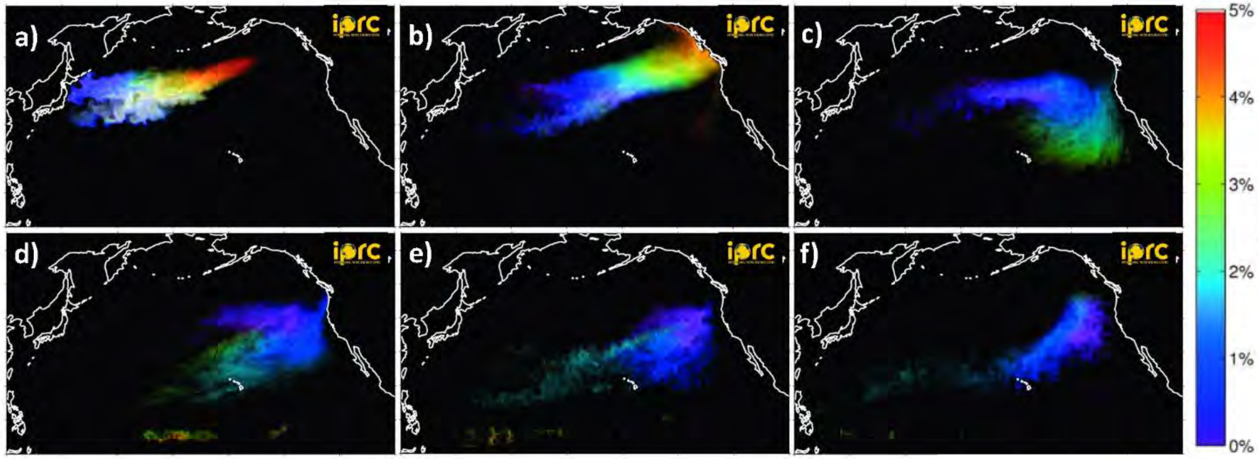
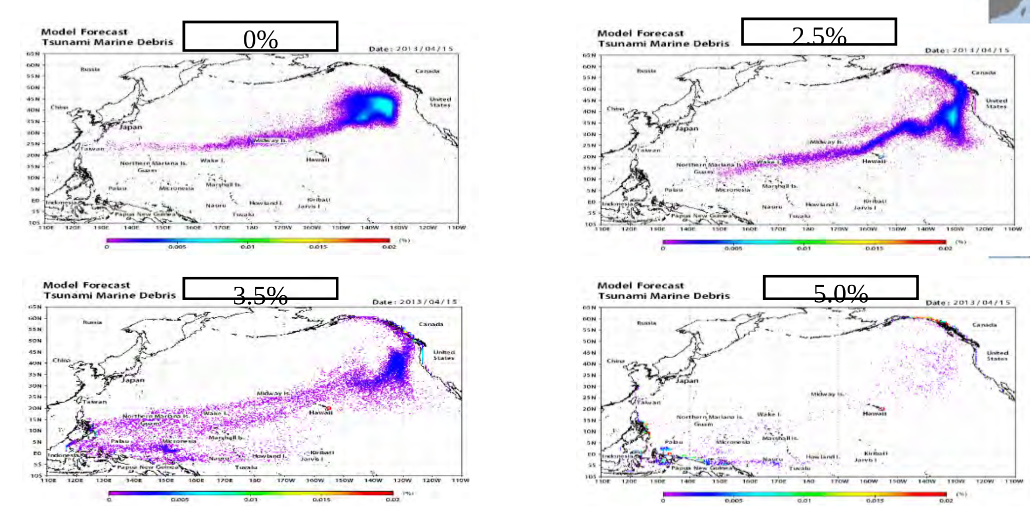
- *Hawaii State DLNR: Barbara Lee and Kirsten Moy*

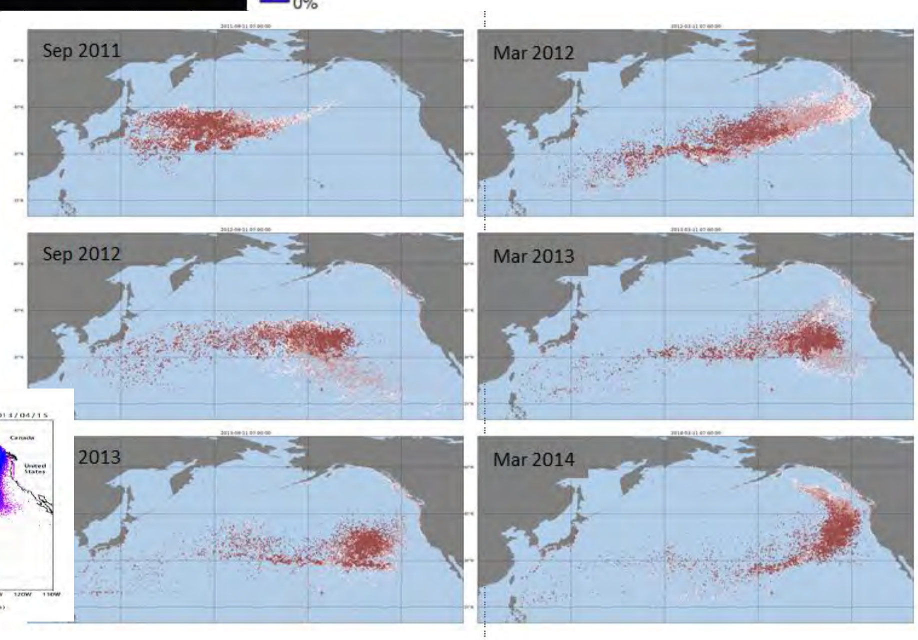
Model simulations used in the ADRIFT project



Motion of JTMD in SCUD model simulations. Colors indicate windage of the debris. Shown are maps for (a) September 1, 2011, (b) March 1, 2012, (c) September 1, 2012, (d) March 1, 2013, (e) September 1, 2013, and (f) March 1, 2014.

April 15, 2013 distributions of SEA-GEARN/MOVE-K7 model particles for four values of windage: 0, 2.5, 3.5, and 5%. Colors indicate concentration of particles on a computational grid.





GNOME modeled particles simulate the movement of tsunami debris of varying types – from high windage objects like styrofoam (white) to low-windage objects like wood (red). These six panels show the distribution of the model particles every 6 months from September 2011 (6 months post-tsunami; top left) to March 2014 (3 years post-tsunami; bottom right).

Airplane disappearance on March 8, 2014

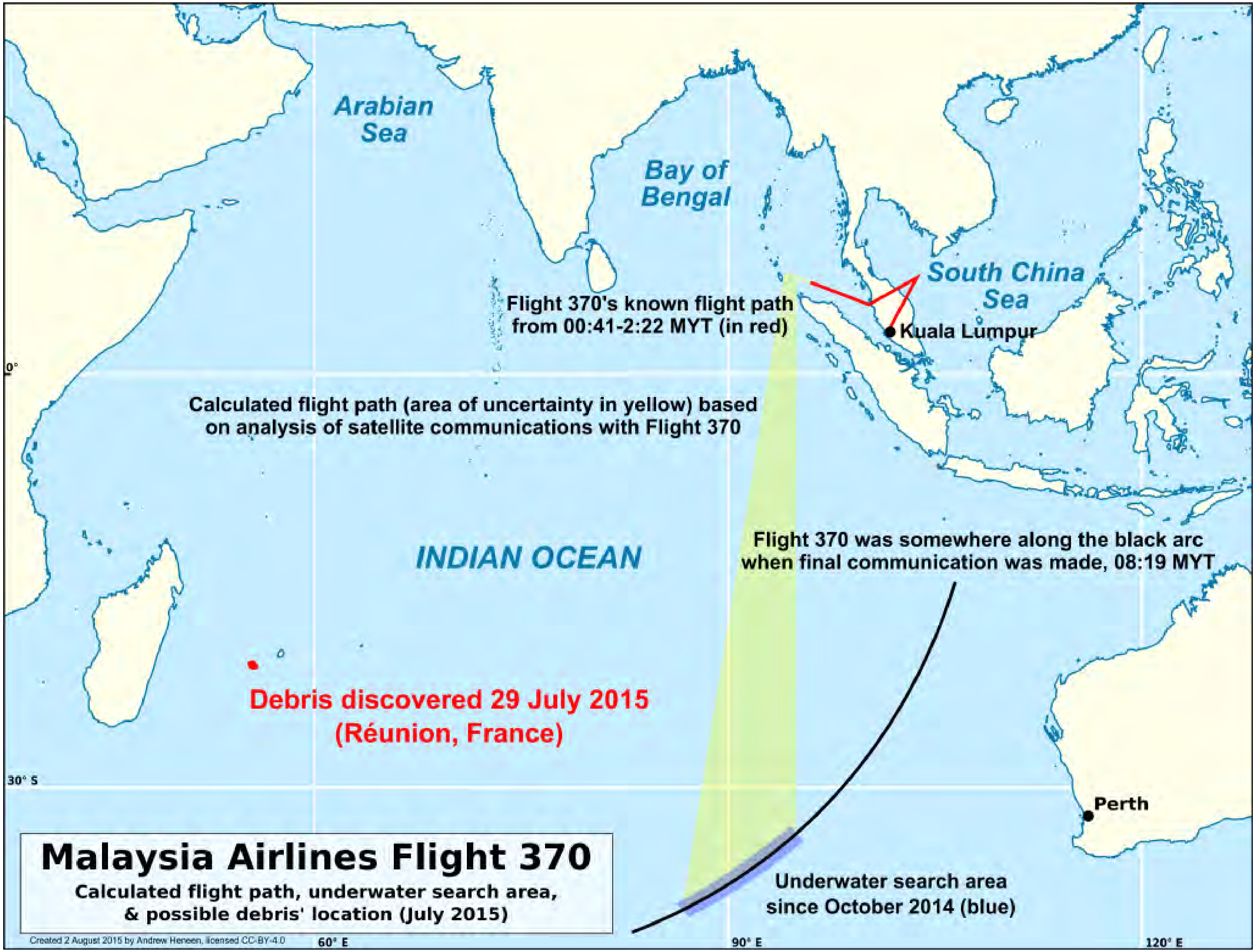
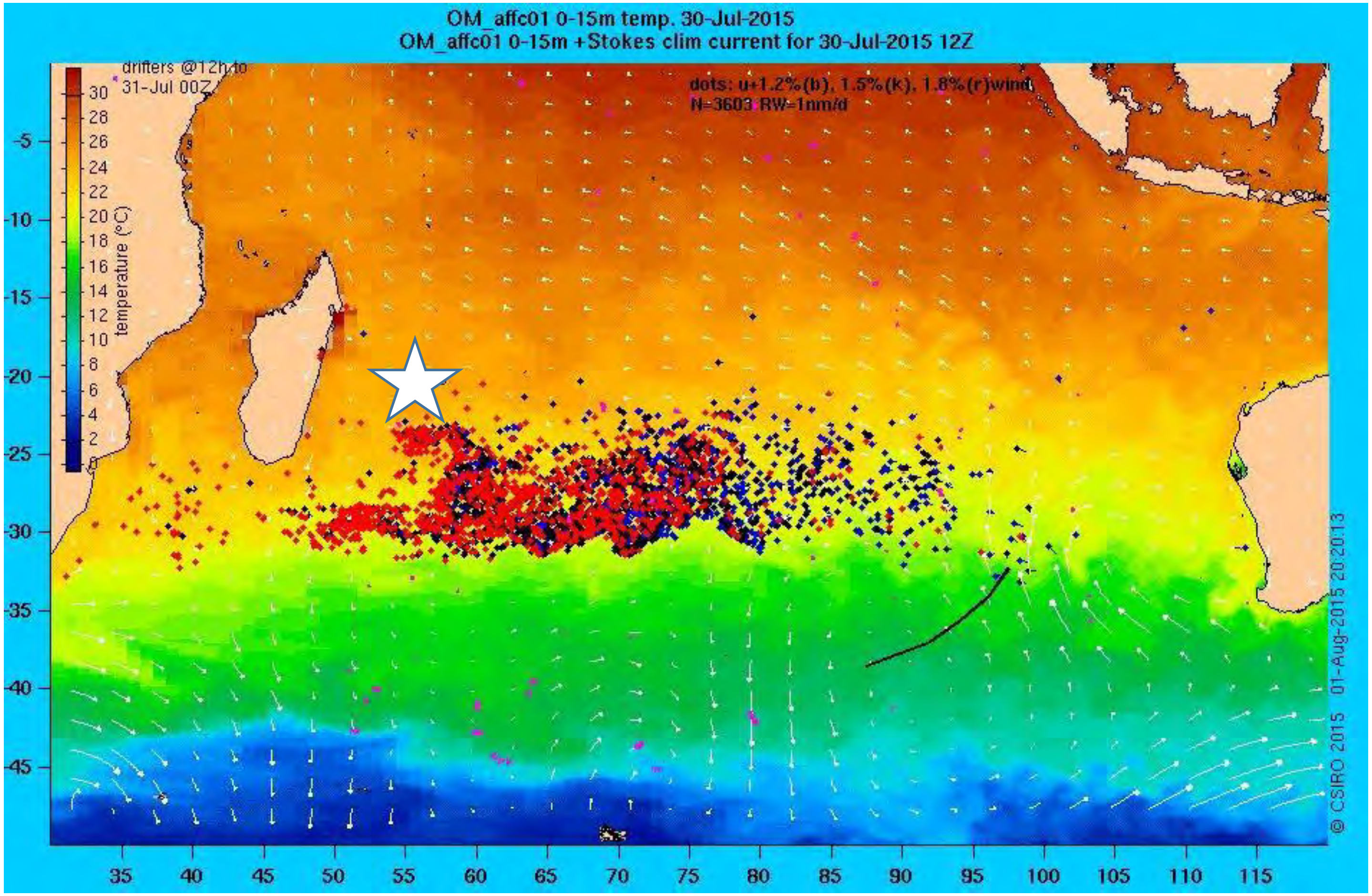


Image source: Andrew Heneen on Wikipedia

Flaperon found on July 29, 2015 on Reunion Island

Image source: Andrew Heneen on Wikipedia

Joint Agency Coordination Center (JACC, Australia) – search update of Aug 5, 2015



Drift modelling by Australia's Commonwealth Scientific and Industrial Research Organisation (CSIRO) shows that material from the current search area could have been carried to La Réunion, as well as other locations, as part of a progressive dispersal of floating debris through the action of ocean currents and wind.

Figure shows the indicative drift of debris from the search area as at 30 July.

Blue, black and red dots simulate items with leeway factors (applied to the 10m wind velocity) of 1.2, 1.5 and 1.8%. The items originated along the black arc (7th arc) on 8 March 2014. White arrows are the winds for the day shown.

Magenta symbols are positions of real drifting buoys (with sea-anchors at 12m) on the day. Their movement has been used to estimate the errors of the ocean current component of the total drift velocity.

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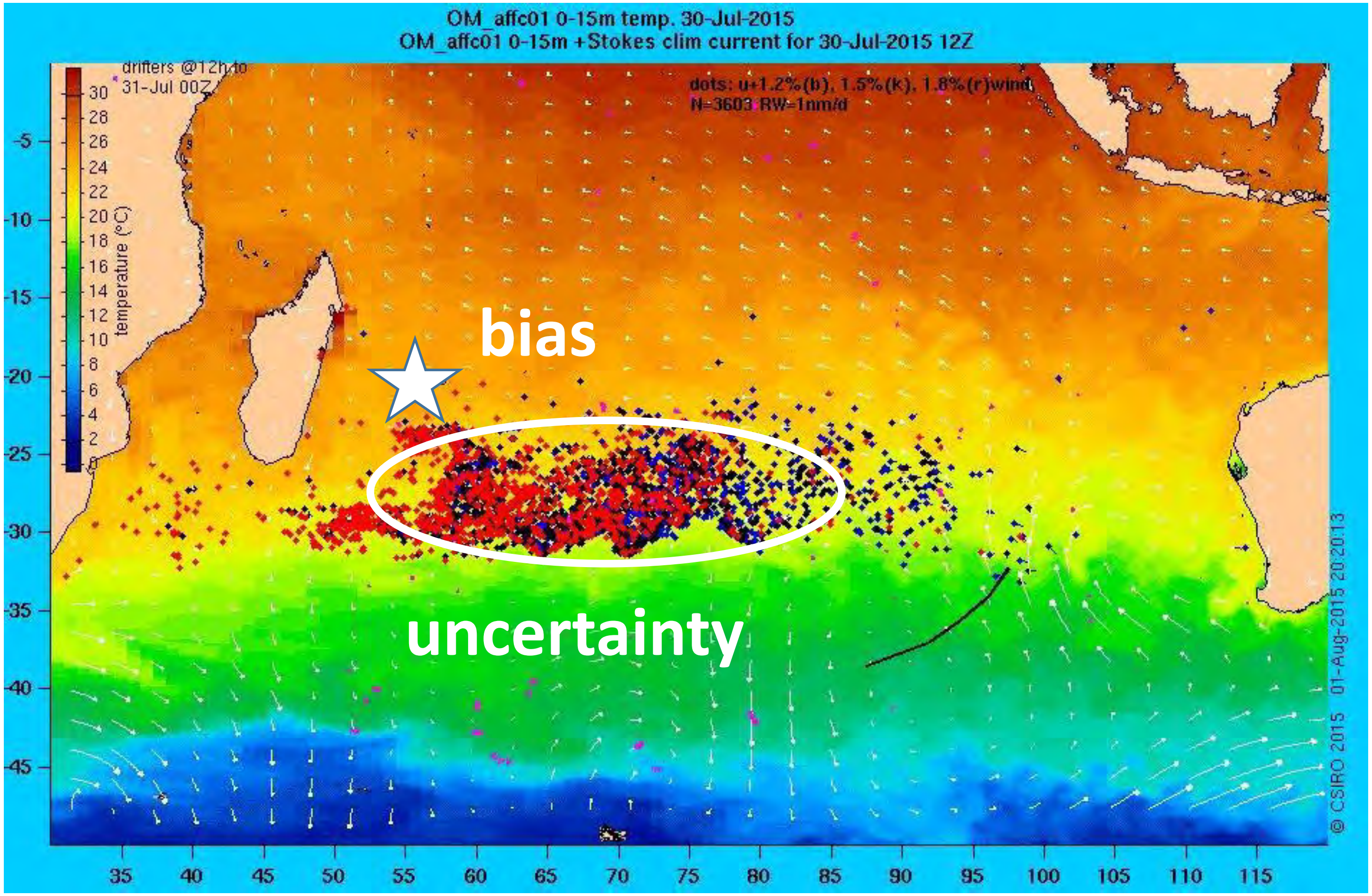

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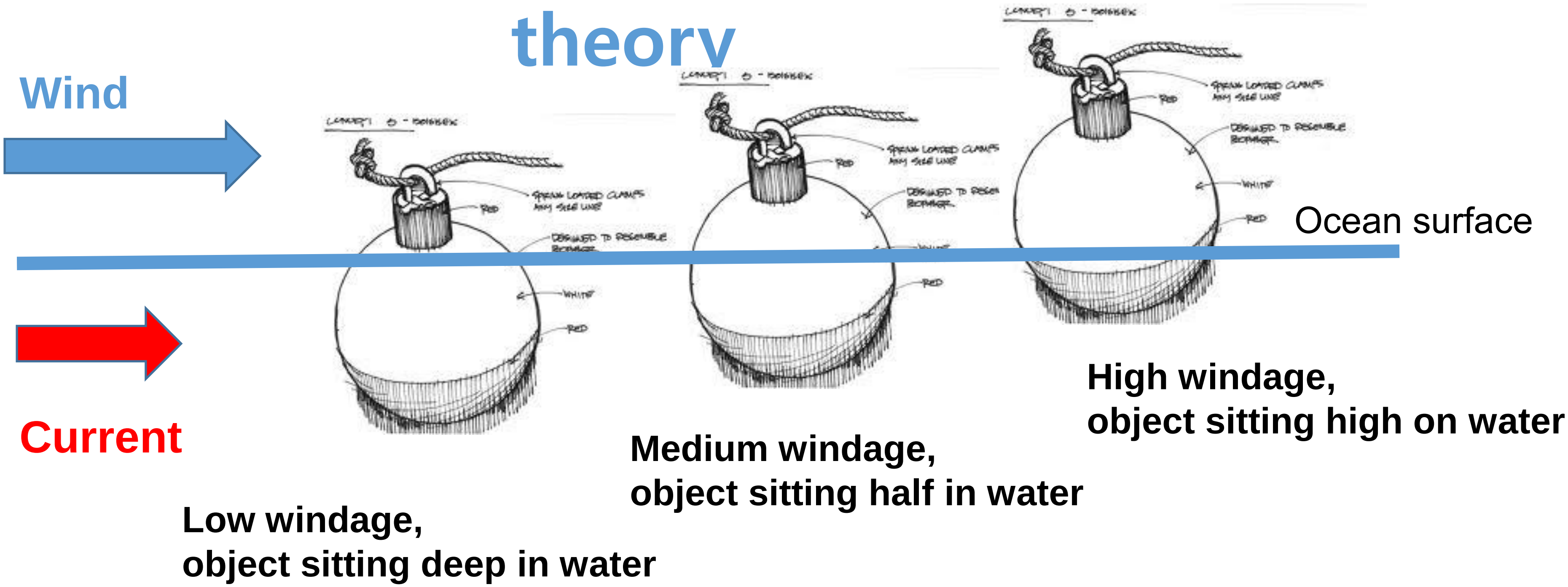
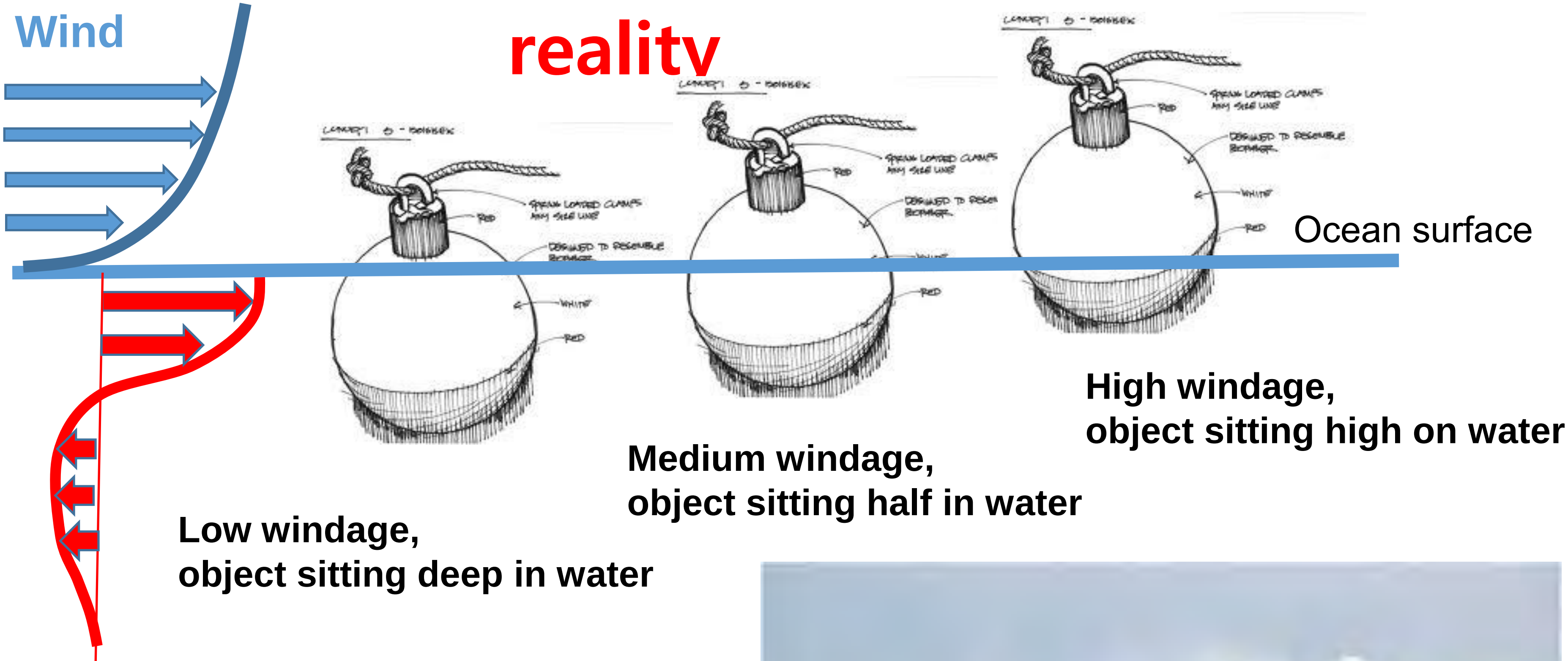
Drift in theory

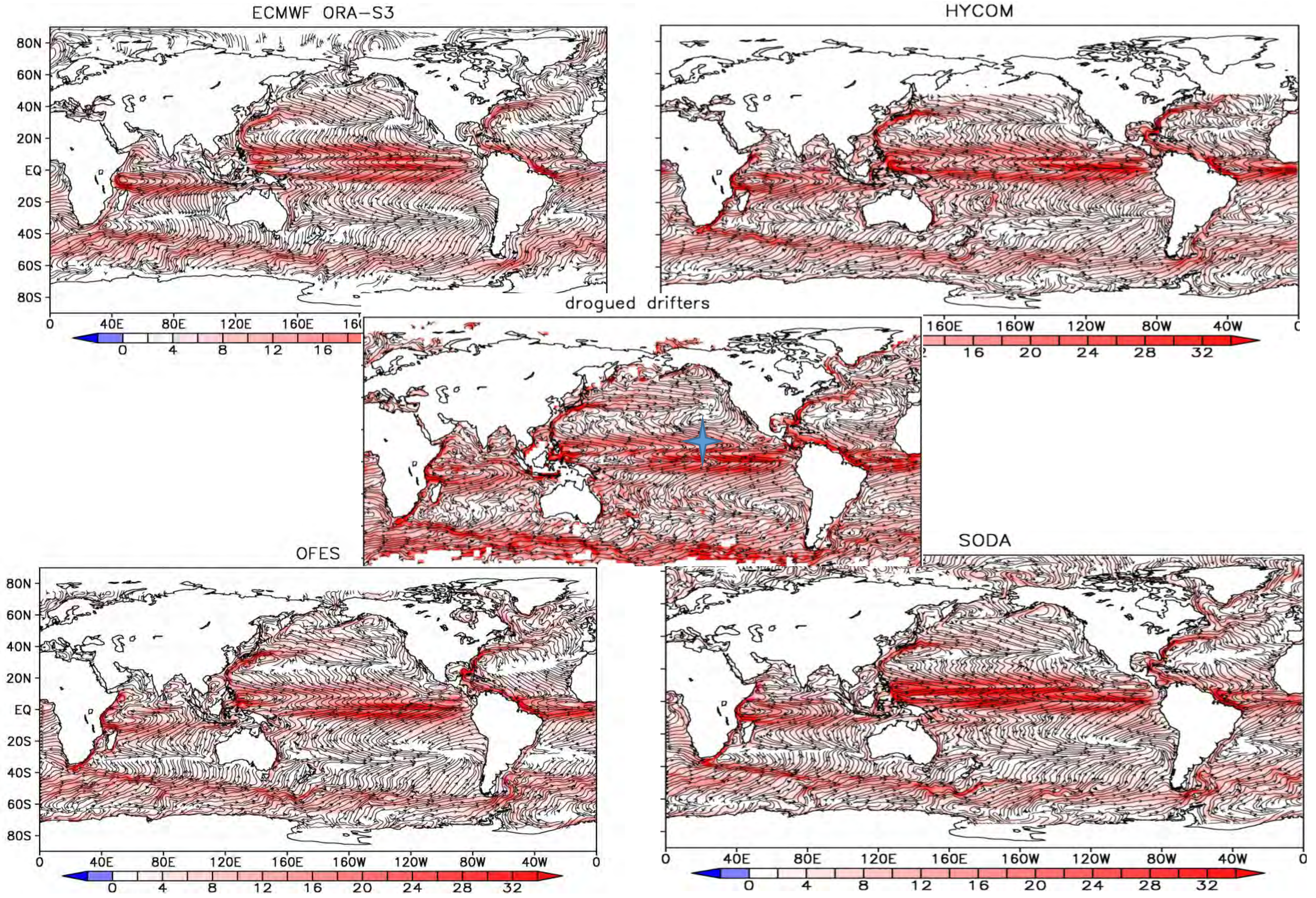


Drift in reality

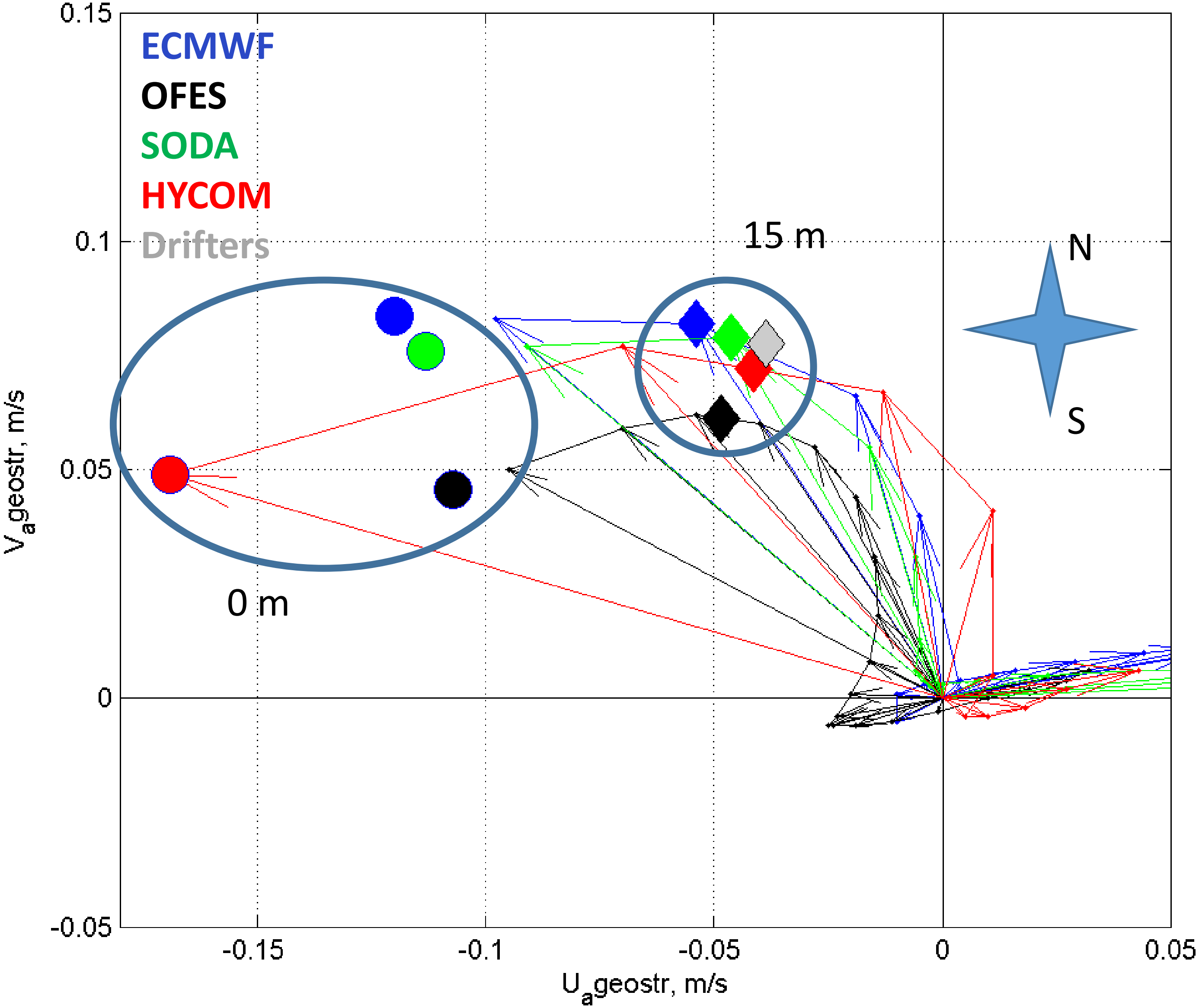


Current is a product of multiple complex mixed layer processes
Mean drift is a result of rectification of high-frequency motions…
… in which floating object does not float on the surface…
… and the very definition of “sea surface” Is difficult.

Time-mean currents at 15 meters level in different models



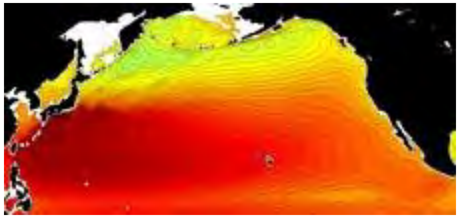
Mean Ekman spirals in the Tropical North Pacific (15N, 140W)



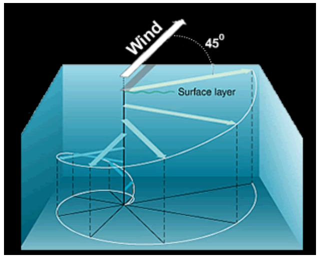
IPRC Drift model

Velocity of debris = Ocean surface current, consistent with drifter trajectories + Deviation fro drifter velocity as a function of wind

Geostrophic currents from satellite altimetry



Ageostrophic currents from satellite wind



Profile above sea surface

Buoyancy: sampling different depth range

SCUD diagnostic model

Assumed to be a function of the wind

Practical formula:

Drift = Current + A(windage)*Wind

(from SCUD) (from satellites or models)

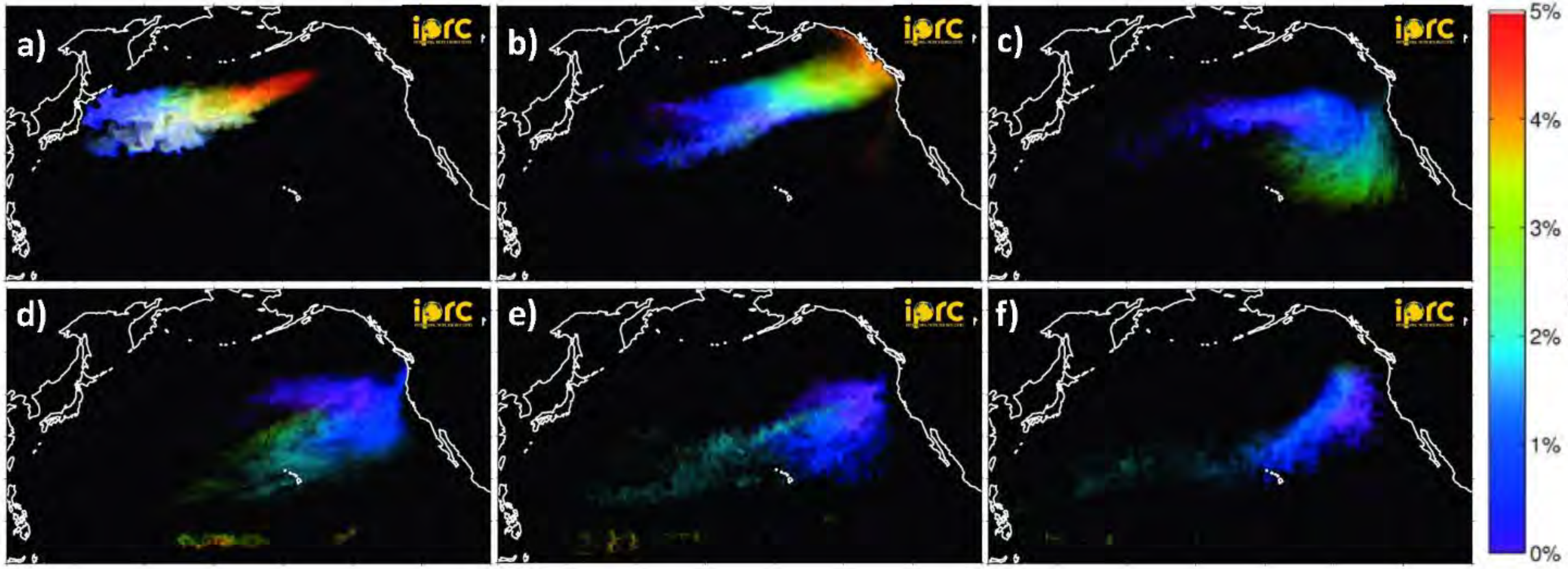
Same object may dynamically correspond to **different windages** in different models

On March 11, 2011 tsunami devastated the east coast of Japan and generated ~1.5 million tons of floating debris, much of which drifted to the North America and Hawaii

Examples of marine debris from March 11, 2011 tsunami in Japan

Photos collected in or near Hawaii

Model simulation of marine debris drift from the March 11, 2011 tsunami in Japan (colors indicate different windages)



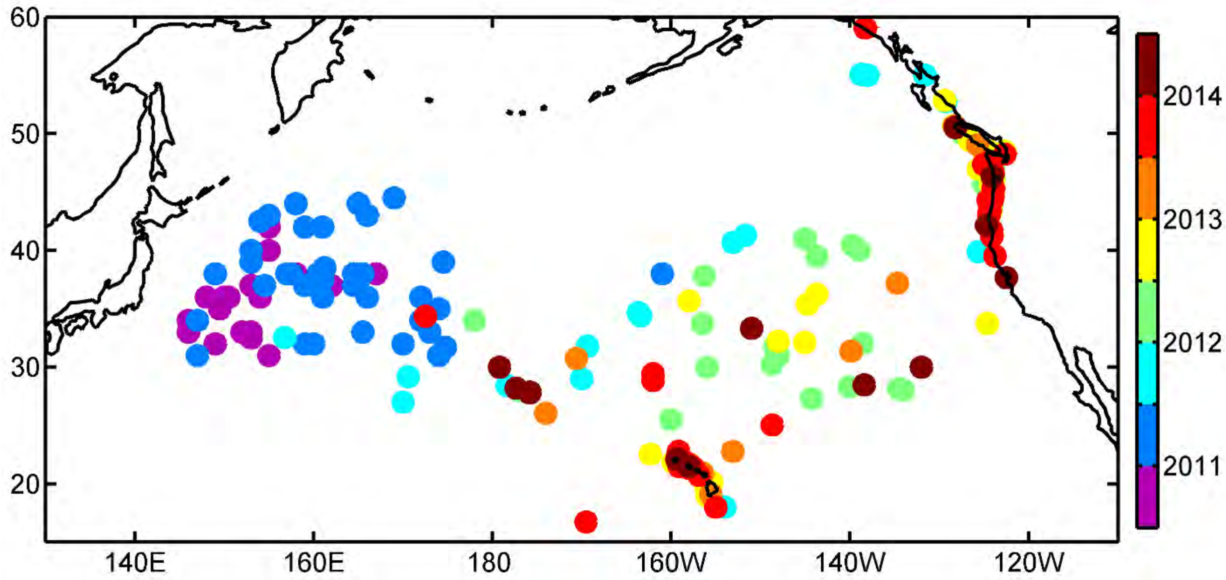
Motion of JTMD in SCUD model simulations. Colors indicate windage of the debris. Shown are maps for (a) September 1, 2011, (b) March 1, 2012, (c) September 1, 2012, (d) March 1, 2013, (e) September 1, 2013, and (f) March 1, 2014.

JTMD is very heterogeneous and dynamical parameters of individual items are largely unknown.

To improve simulations of JTMD drift we:
- narrowed the analysis to particular categories (addressed in this presentation are boats and skiffs);
- developed probabilistic technique that allows to estimate unknown windage and probable trajectories of individual objects or their ensembles.

The technique is based on tracer concentration (rather than particle) experiments and the concentration is interpreted as a probability density function of the particle position.

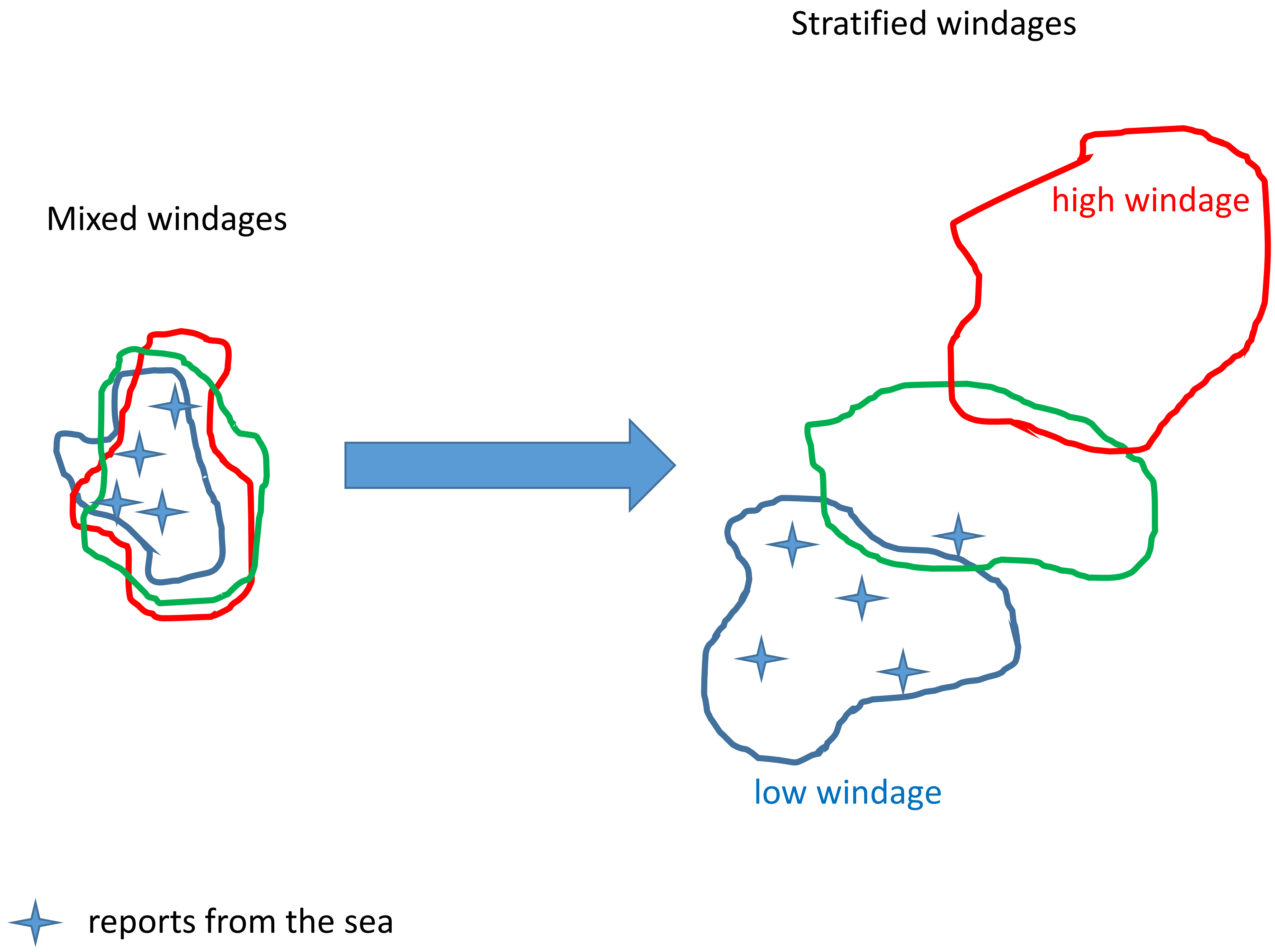
Dataset, compiled using reports from multiple sources



277 reported locations of boats/skiffs/ships and (colors) times of the reports. Color bar spans January 2011–December 2014 and labeled ticks mark central moments of the years.

Problems are:

- data distribution is strongly biased to the pattern of observing ships
- ‘clean’ areas are not reported


Stratified windages
Mixed windages
high windage
low windage
reports from the sea

Determining optimal windage

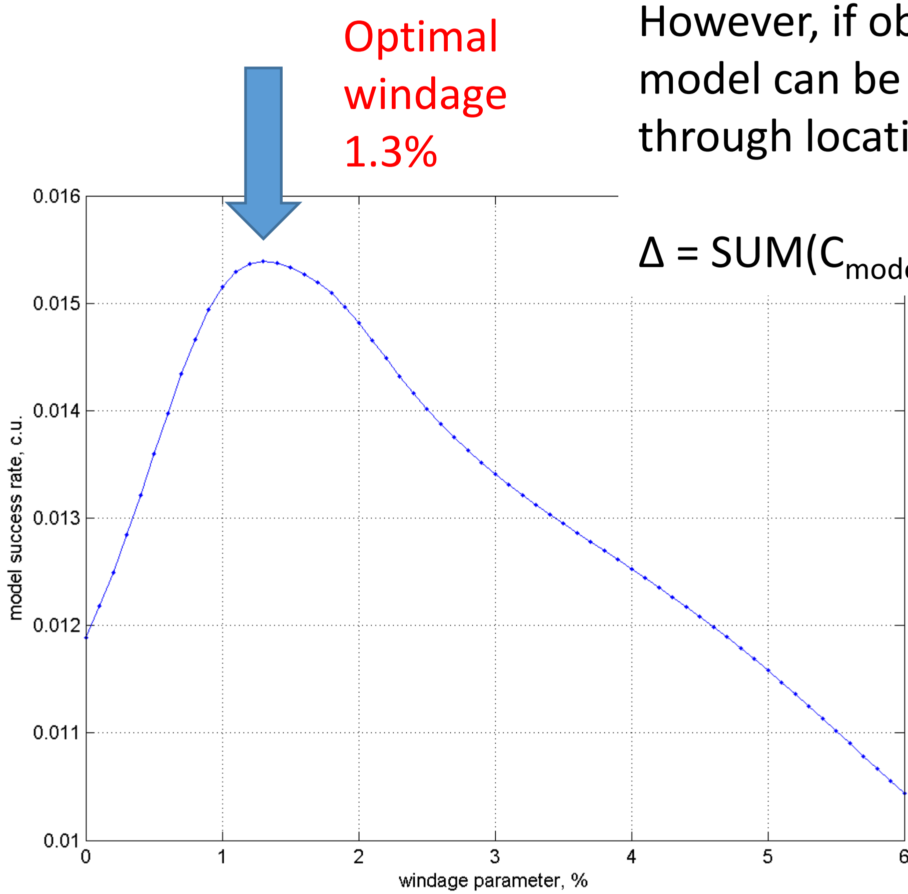
Ideally, to validate model we would compare density of model tracer with observed density of debris, e.g., through:

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

and optimal windage would correspond to minimum Δ.

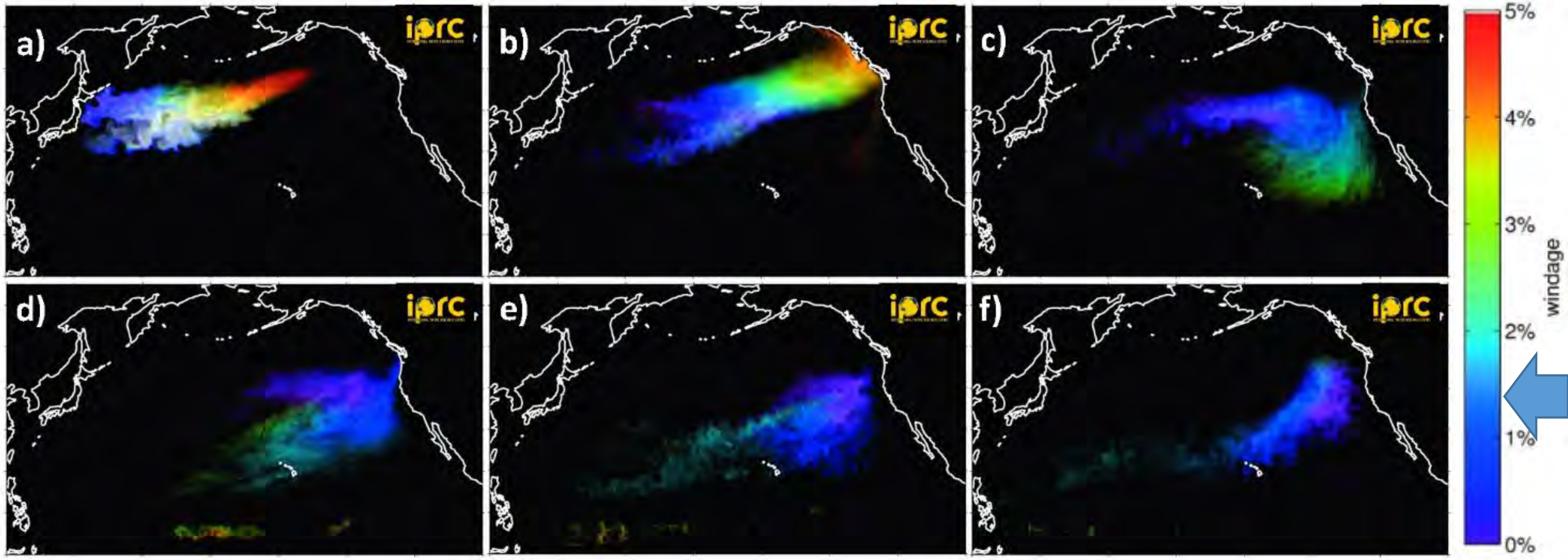
However, if observations are 'independent', success of the model can be estimated integrating model concentration through locations/times of real observations:

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



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.

Model simulation of marine debris drift from the March 11, 2011 tsunami in Japan (colors indicate different windages)



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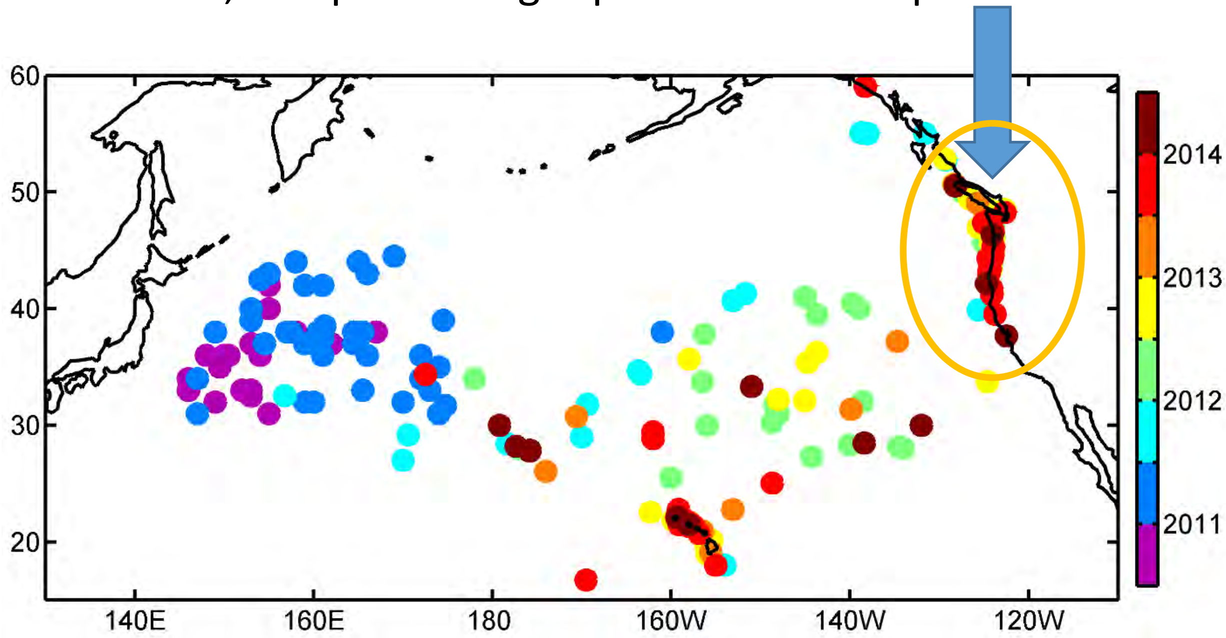

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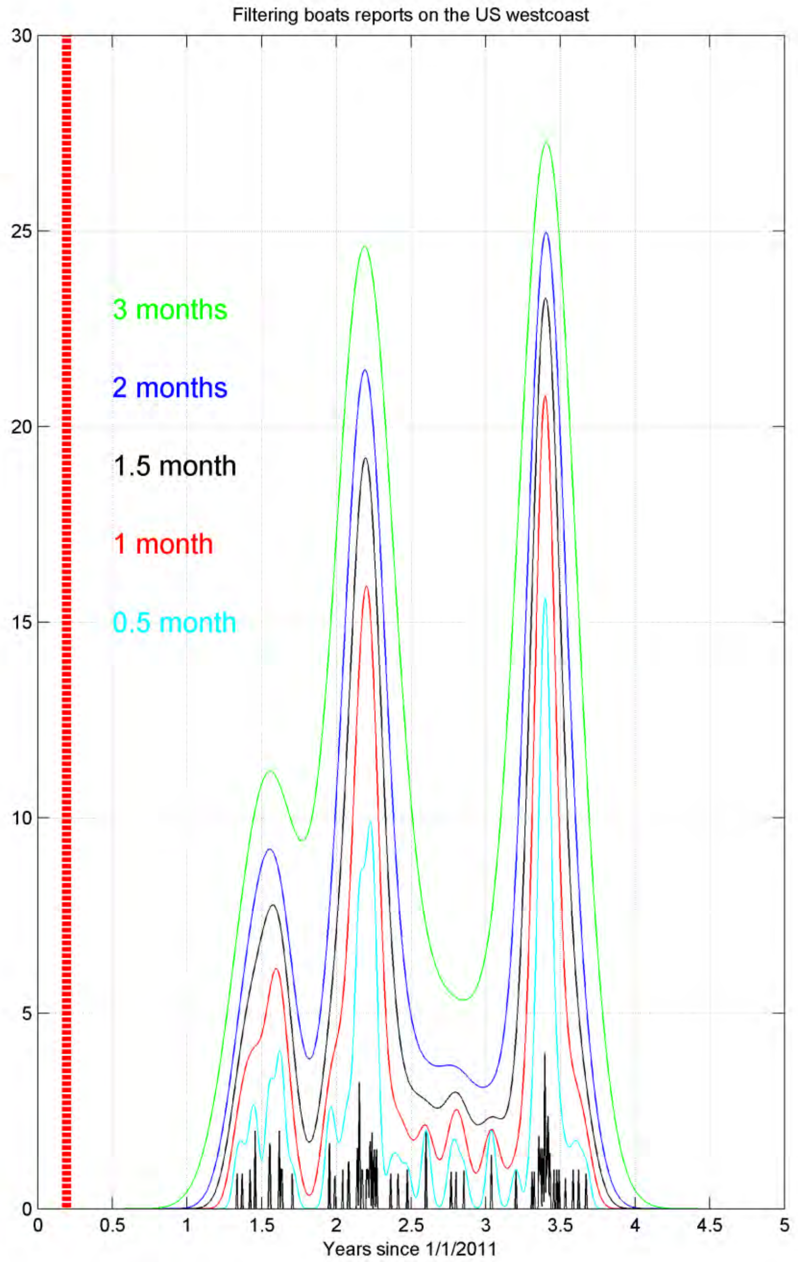
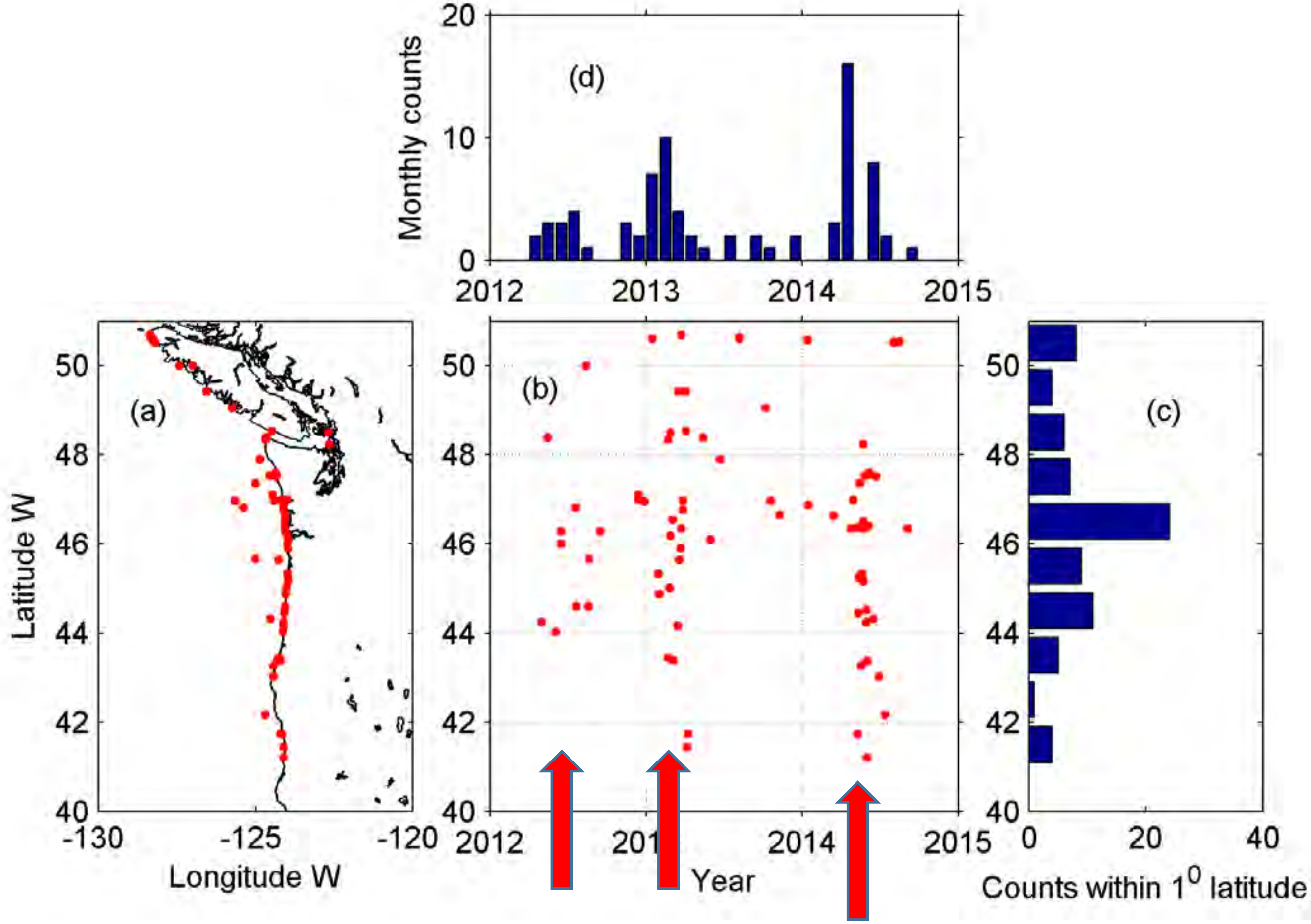
79 reports from the US/Canada west coast.

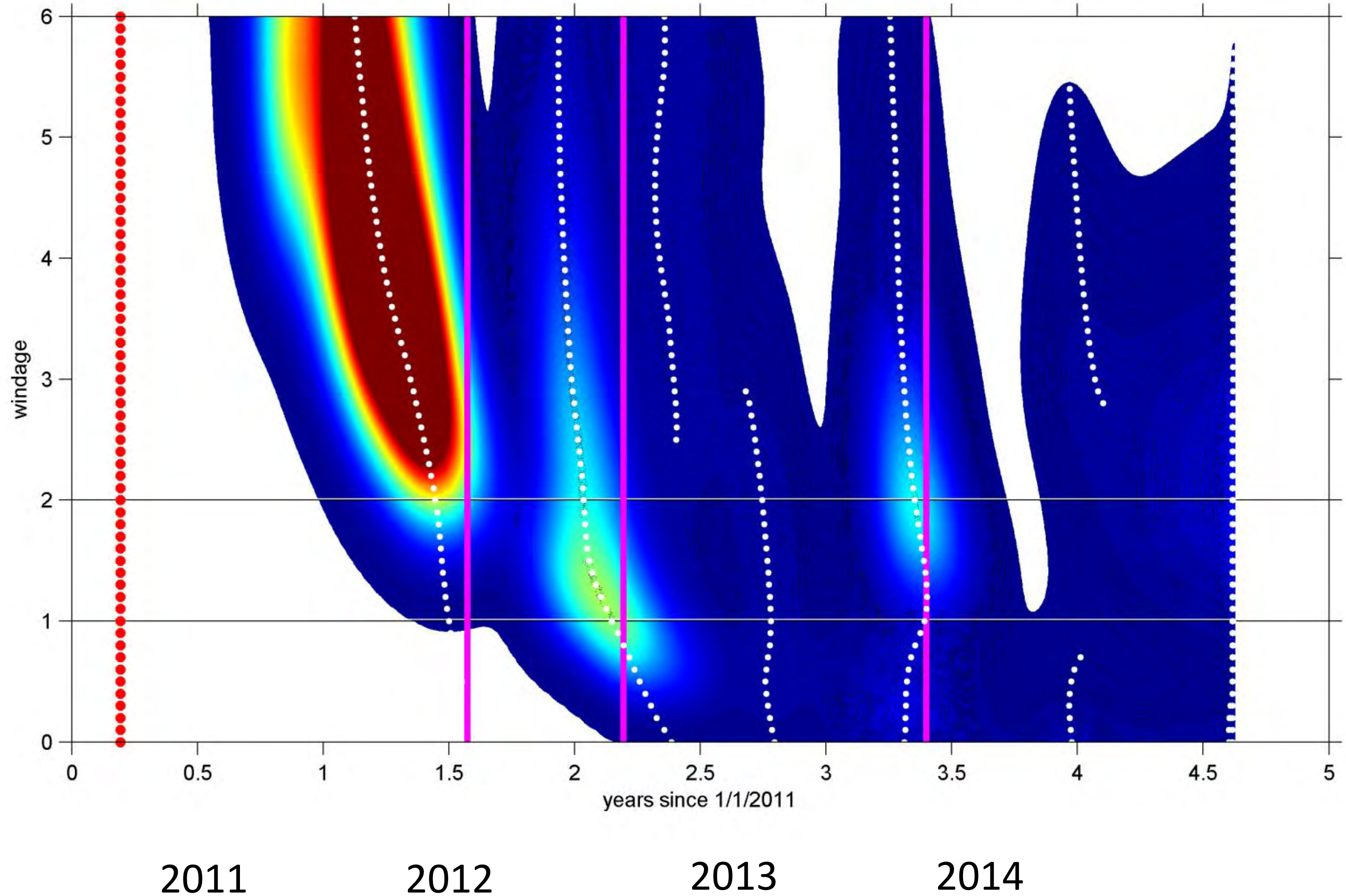


Monthly boat reports from the US/Canada west coast and smoothed indices.

Latitude-time distribution of 79 boat reports on the US/Canada west coast

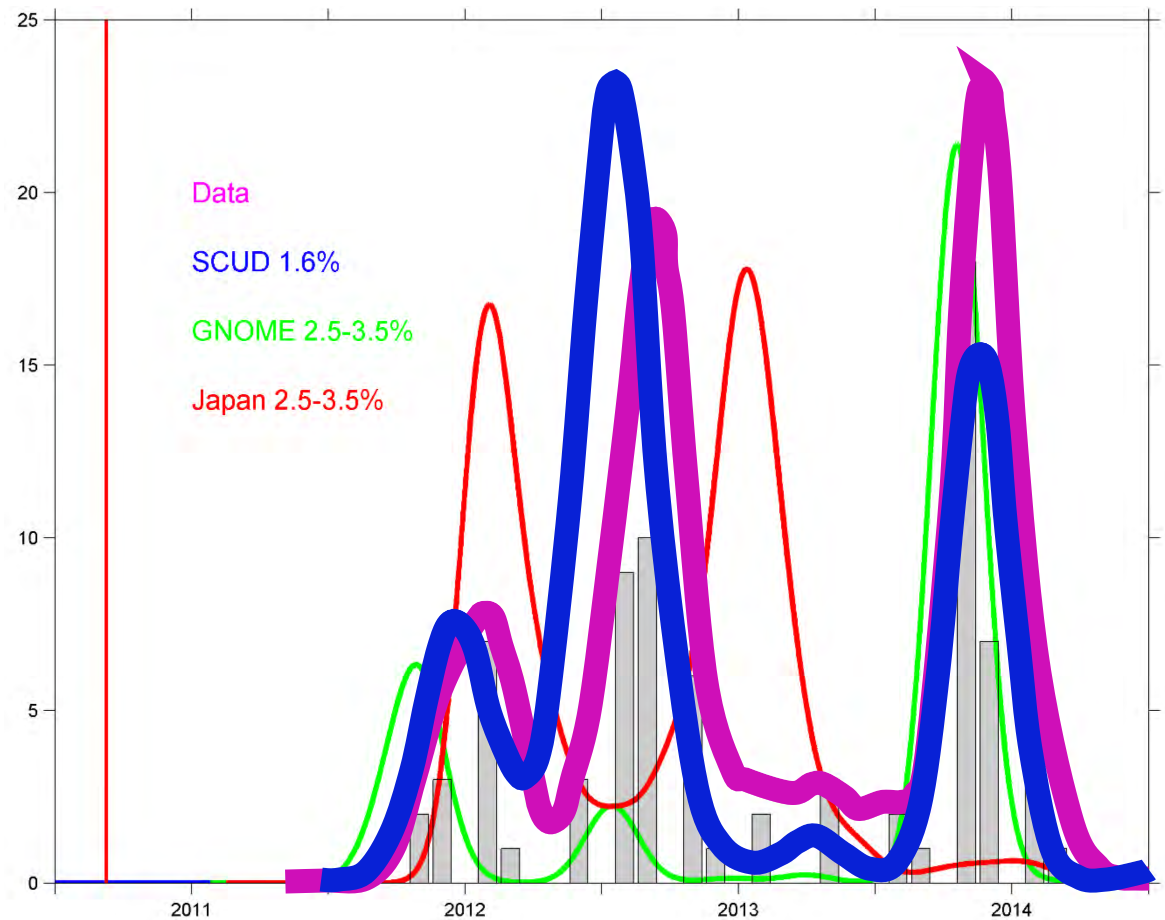


Even small number of reports is enough to outline three distinct peaks – partly because "waves of boats" are highly correlated in latitude and appear synchronously From British Columbia to California.



Timelines of SCUD model fluxes on the US/Canada west coast for a range of windages.

Low-pass filtered in time.



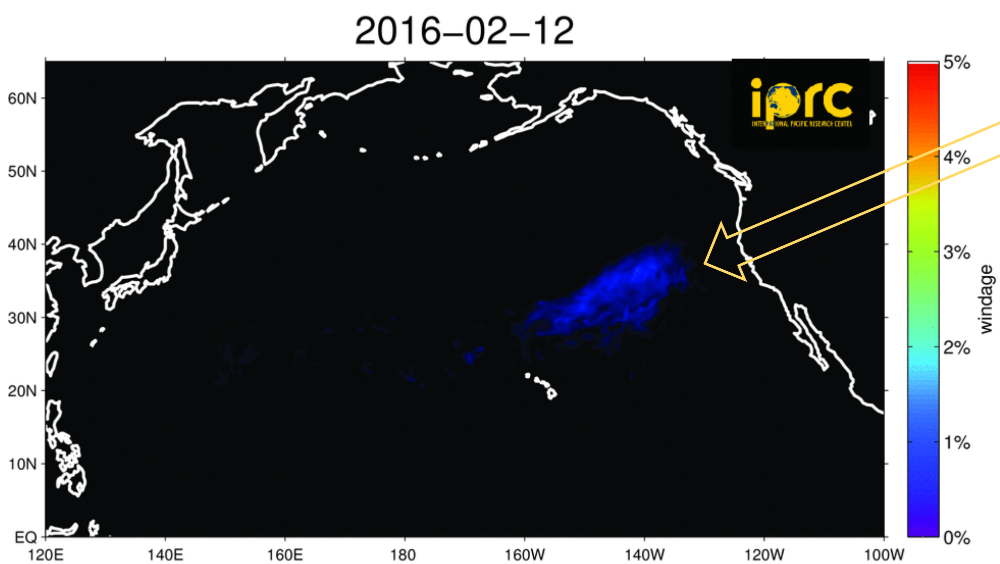
Monthly counts of boats on the U.S./Canada west coast (gray bars) and low-pass filtered timelines of boat fluxes in observations (magenta) and model experiments with different windages: 1.6% for SCUD (blue) and 2.5–3.5% averages for GNOME (green) and SEA-GEARN/MOVE-K7 (red). Vertical red line marks March 11, 2011. Units on y-axis are boat counts for monthly reports and conventional for other timelines.

Conclusions based on model-data comparison

- About 1000 boats were originally washed offshore by the 2011 tsunami.

Consistent with this estimate, on November 16, 2011, the Japan Coast Guard detected 506 skiffs/vessels, drifting off the devastated shoreline.

- 50% of the boats are still floating in the "garbage patch" and will continue washing ashore in the next decade or so.

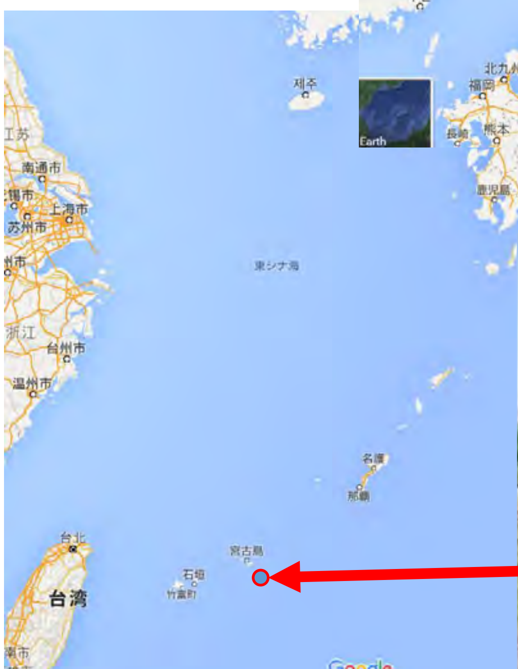


Source: Maximenko & Hafner, IPRC/SOEST, Univ. of Hawaii

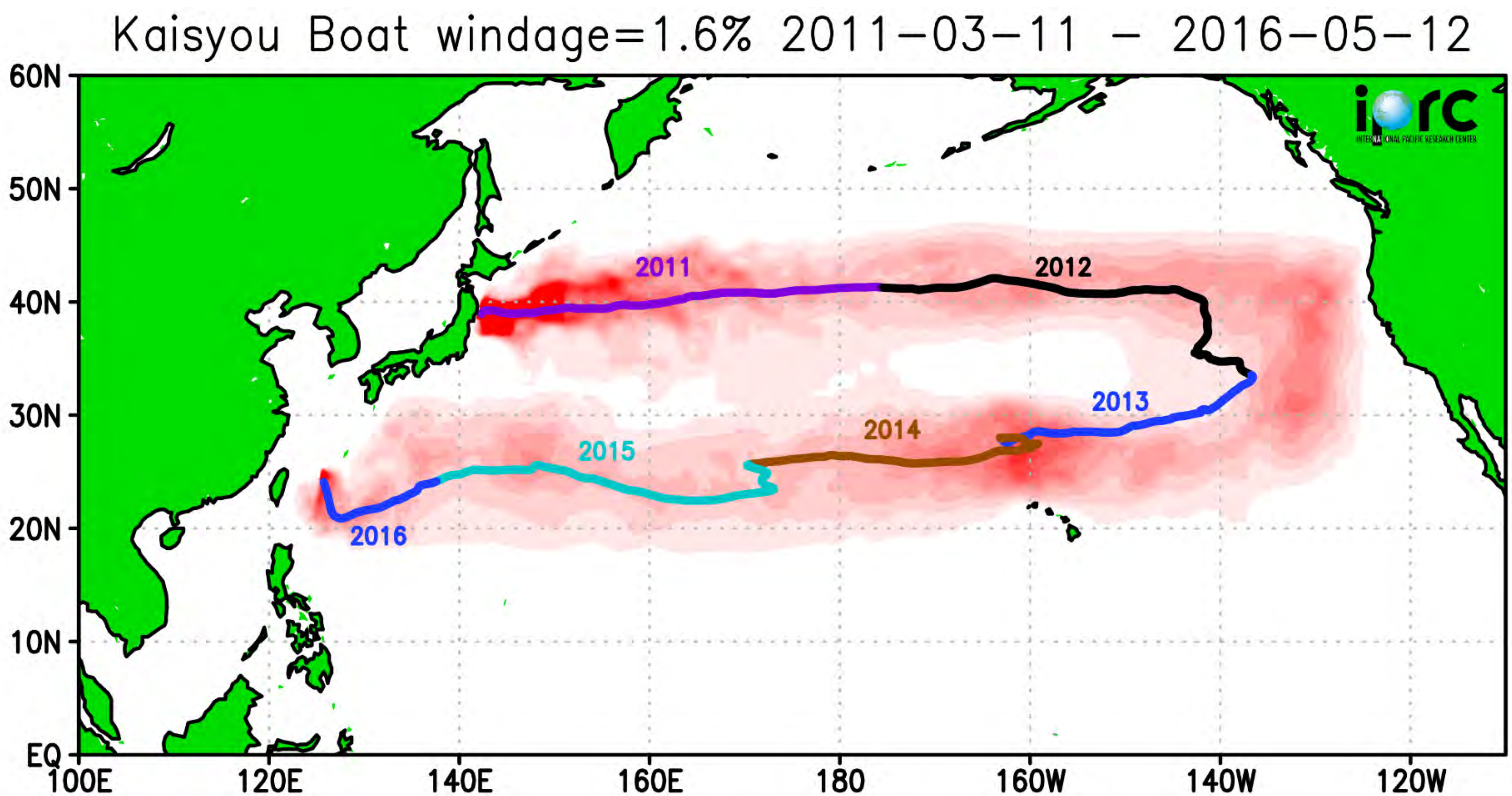
The drift model optimized to the windage parameter and scaled to practical units estimates the probability to observe a JTMD boat from a ship sailing between the US west coast and Hawaii as 0.1-0.5%.

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 Kasyou



The calculation is based on combination of forward and backward simulations

$$PDF(x,y,t|x_s,y_s,t_s|x_e,y_e,t_e) \sim C_{forward}(x,y,t|x_s,y_s,t_s) \cdot C_{backward}(x,y,t|x_e,y_e,t_e)$$