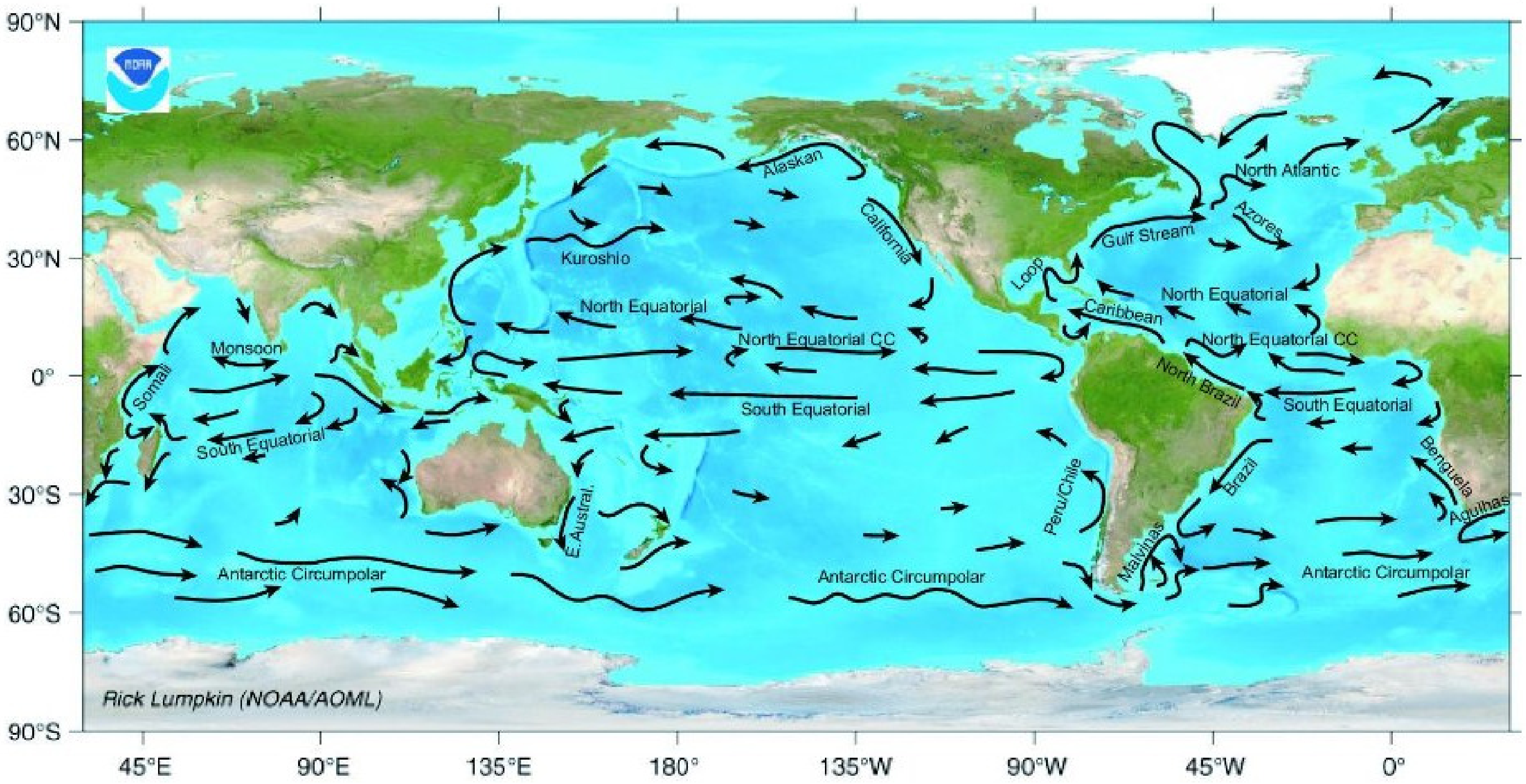
Ocean Surface Currents



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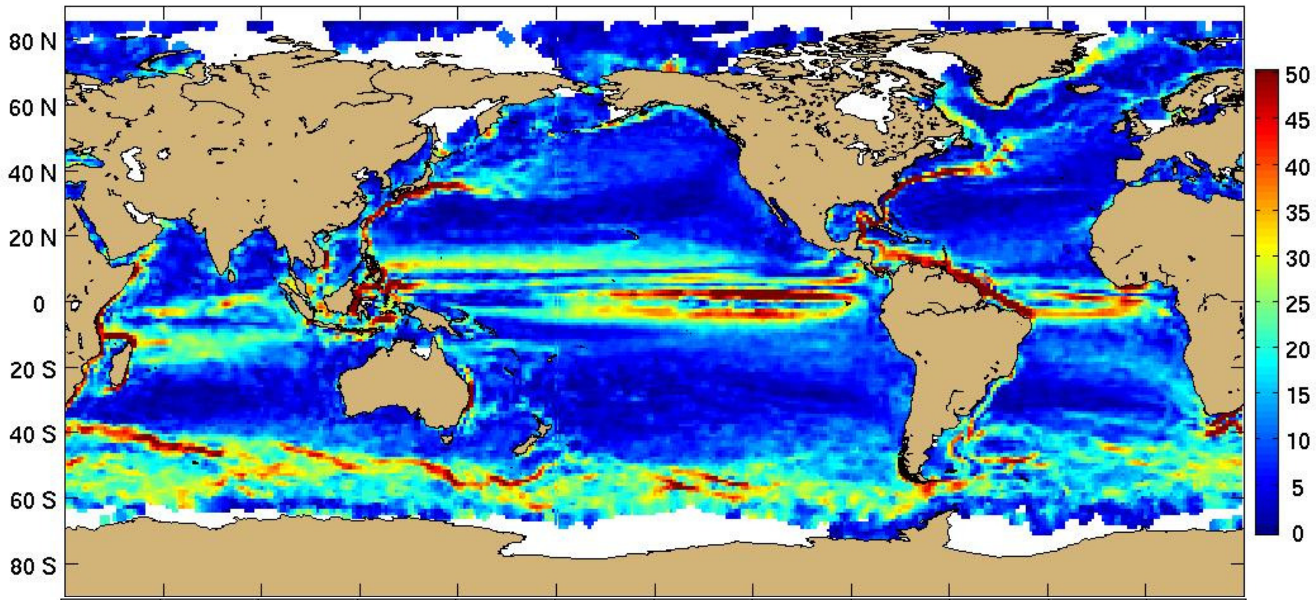
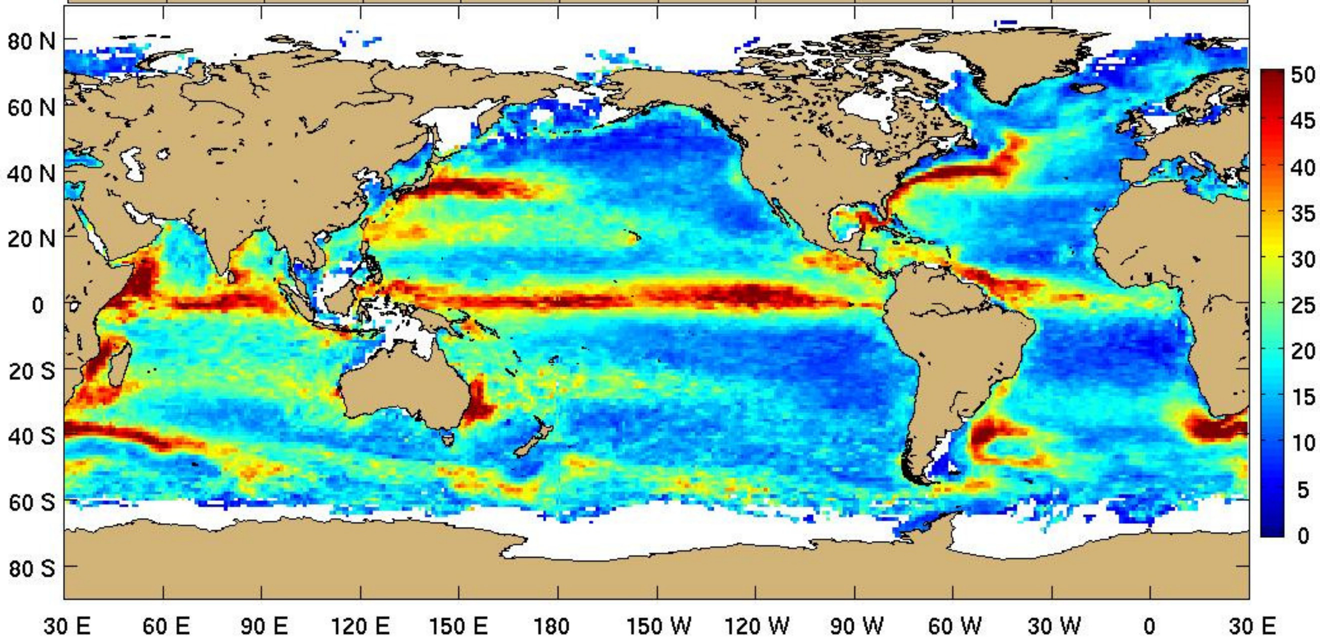
What we know well, and what we don’t …

Mapping ocean currents with in-situ observations



Average speed of surface currents (cm/s)



Root-mean-square variability of currents (cm/s)

Mapping the Kuroshio Current

(in situ + remote)

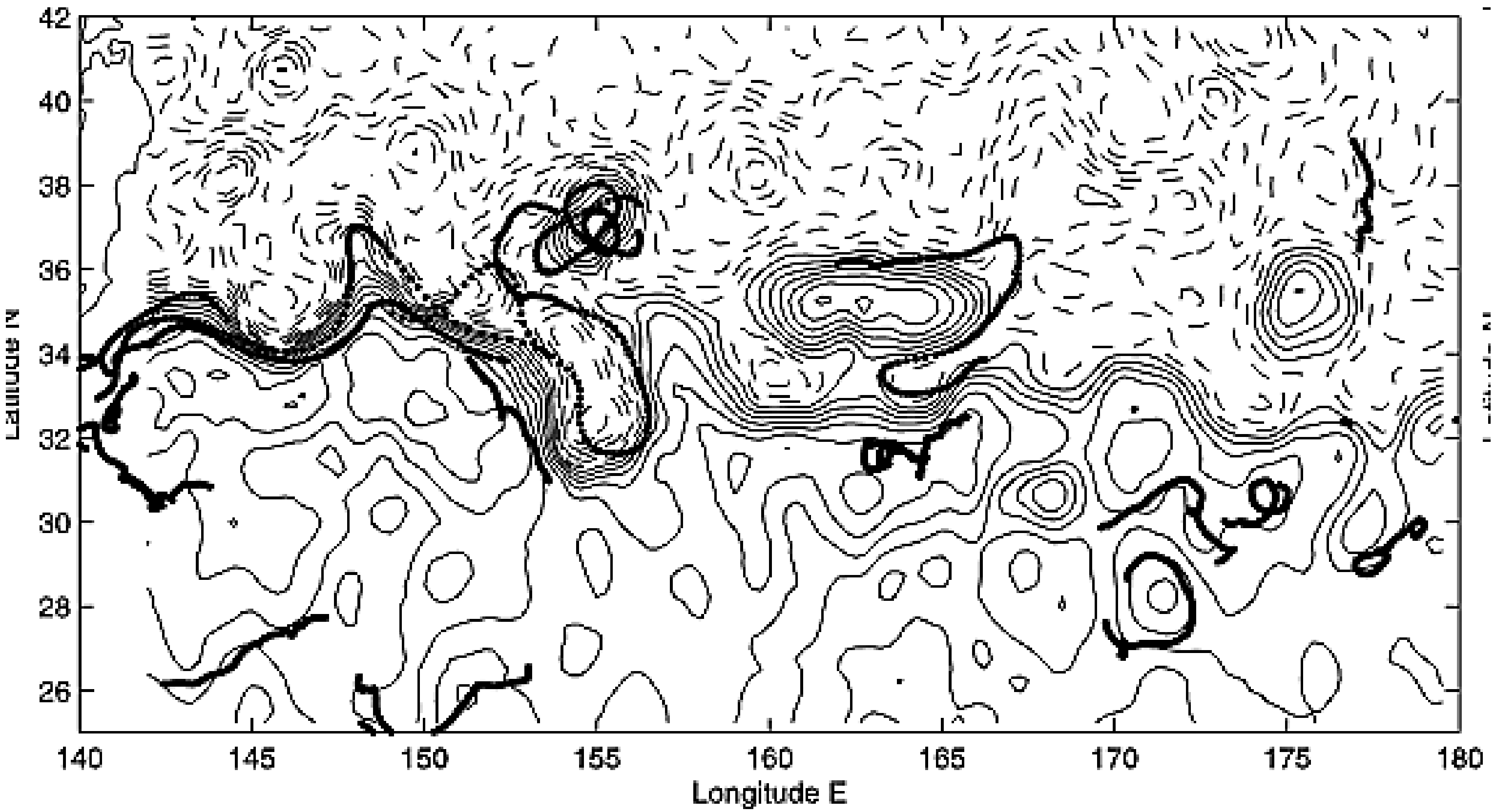
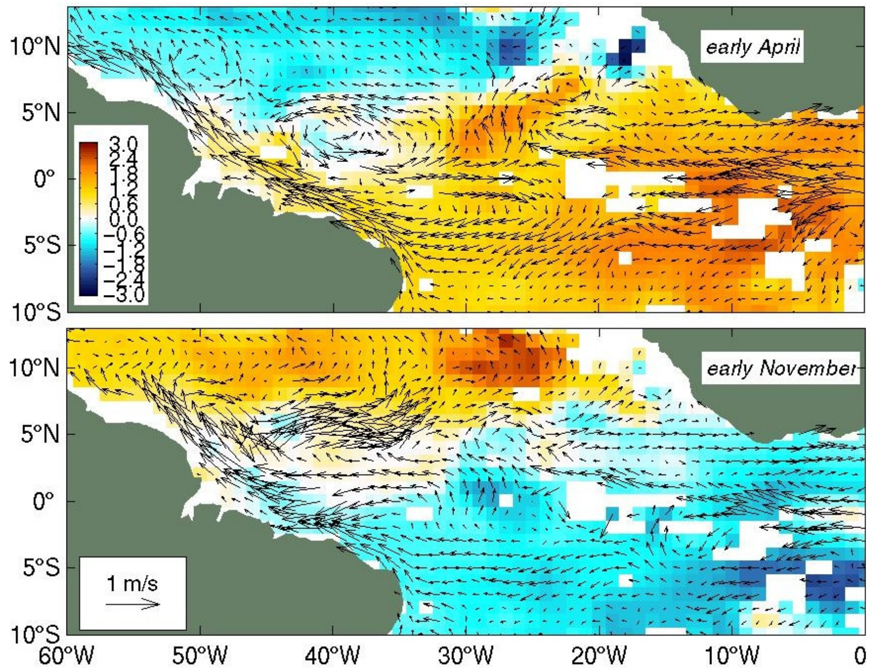
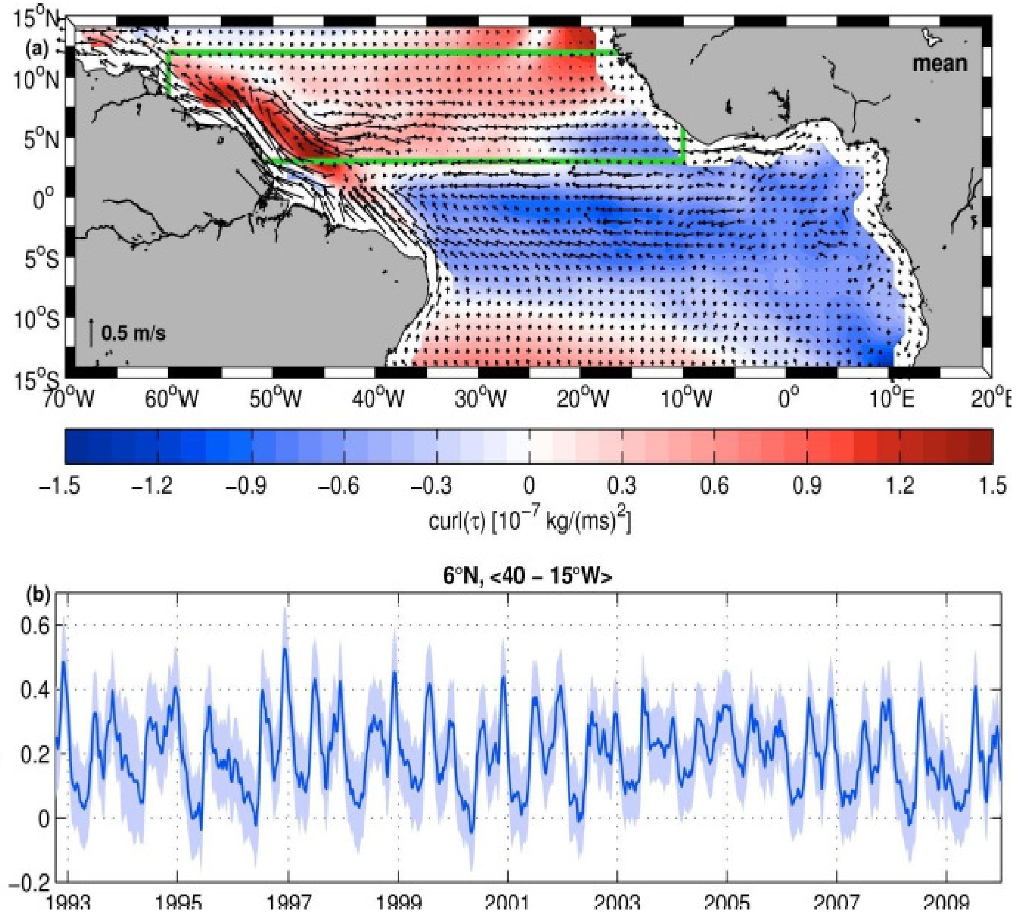


Image: Absolute sea level (area-mean subtracted) on 6 December 1993 computed from altimetry, drifters and wind (contours; interval is 10 cm), and trajectories of drogued drifters (solid black curves) from 16 November to 16 December 1993. From Niiler et al. (2002).

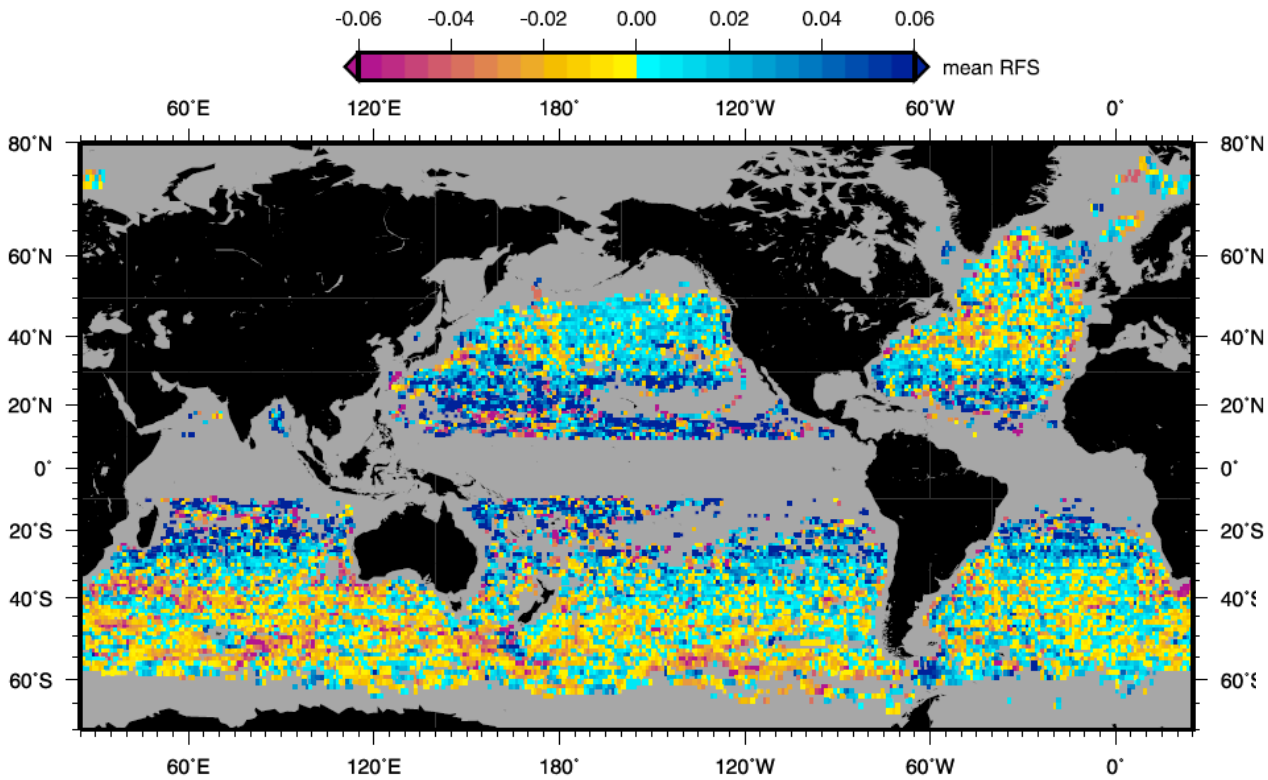
Seasonal to interannual variations



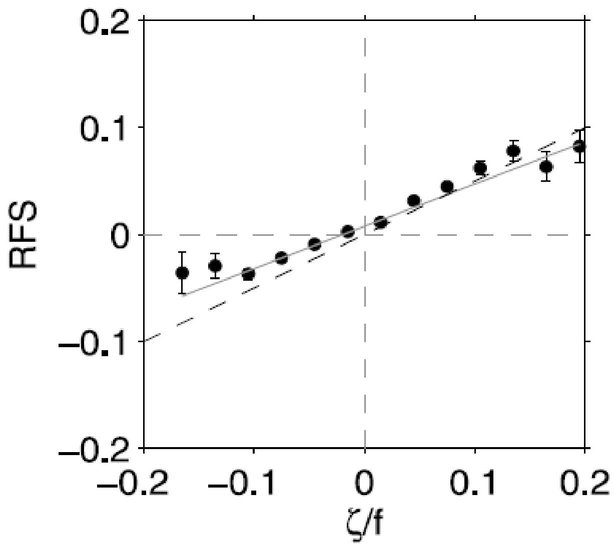


Left: Seasonal variations of surface currents in the tropical Atlantic ocean, mapped from drifter observations (Lumpkin and Garzoli, 2005). **Right**: Interannual variations of the North Equatorial Countercurrent (in green box, superimposed on mean wind stress curl) from a synthesis of drifters, winds and altimetry (Hormann *et al*., submitted).

Near-inertial waves and internal tides: energy input for diapycnal mixing

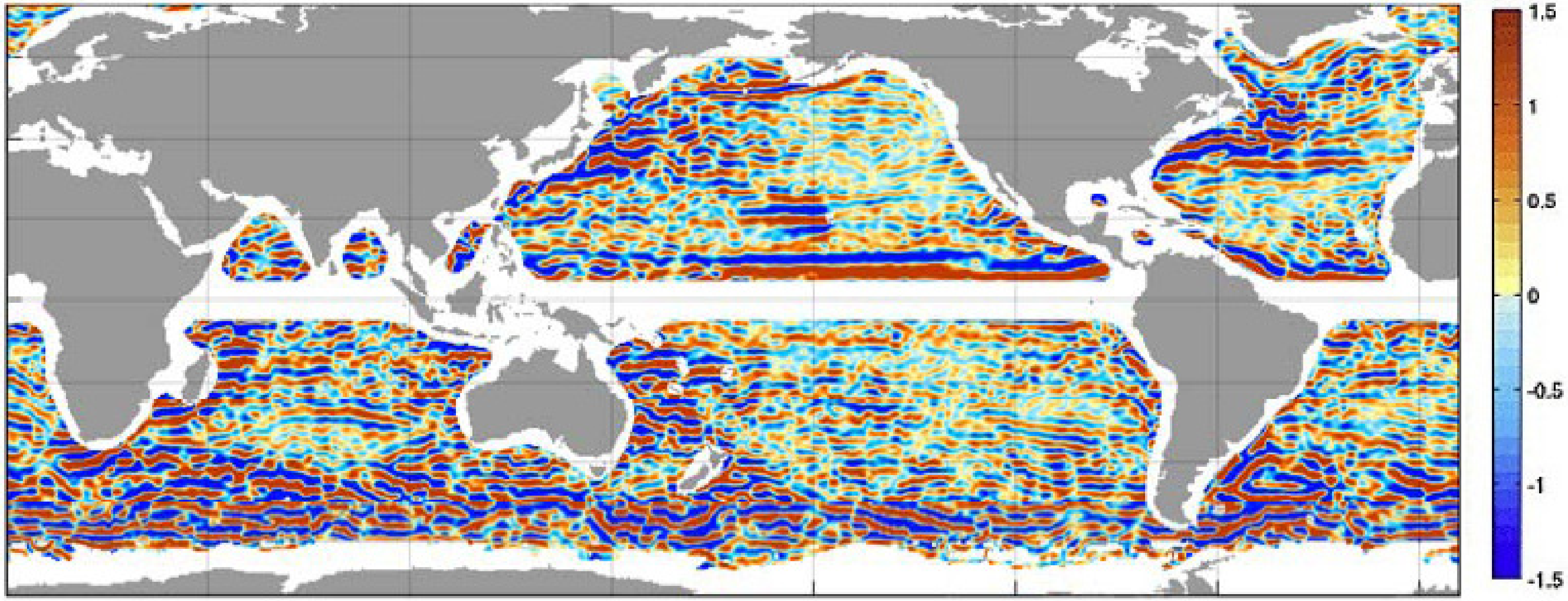


Left: relative frequency shift of near-inertial oscillations from the local inertial period (Elipot et al., 2010).

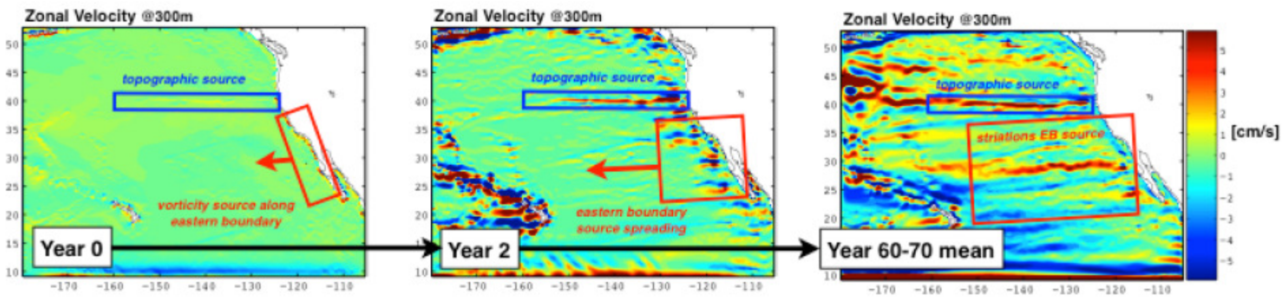


Right: relative frequency shift (vertical, from drifters) vs. background vorticity from altimetry (horizontal) (Elipot et al., 2010). The dashed line indicates the theoretical expectation (Kunze, 1985).

Ocean striations



Maximenko et al. (2008): MDT from GRACE, drifters, altimetry and winds. Highpass at 4°.

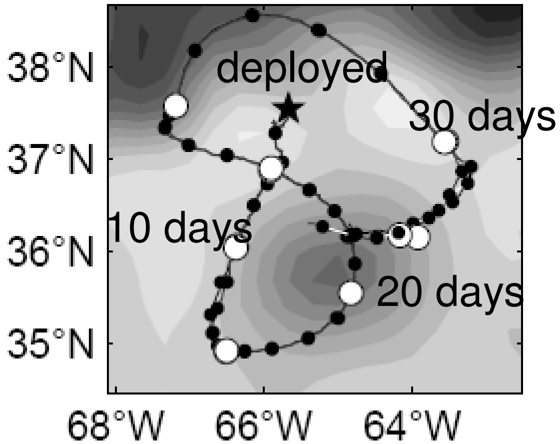


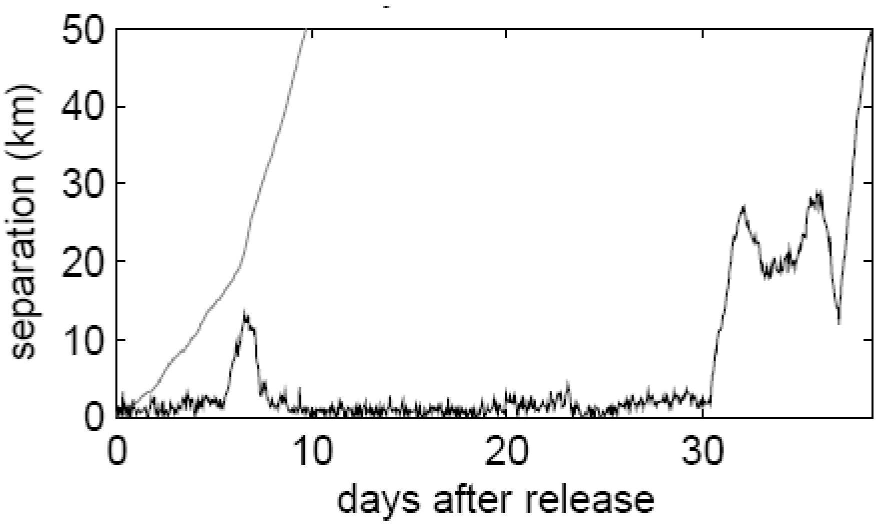
Emergence of beta-plum striations in ROMS simulation of the California Current System (Maximenko et al, 2010).

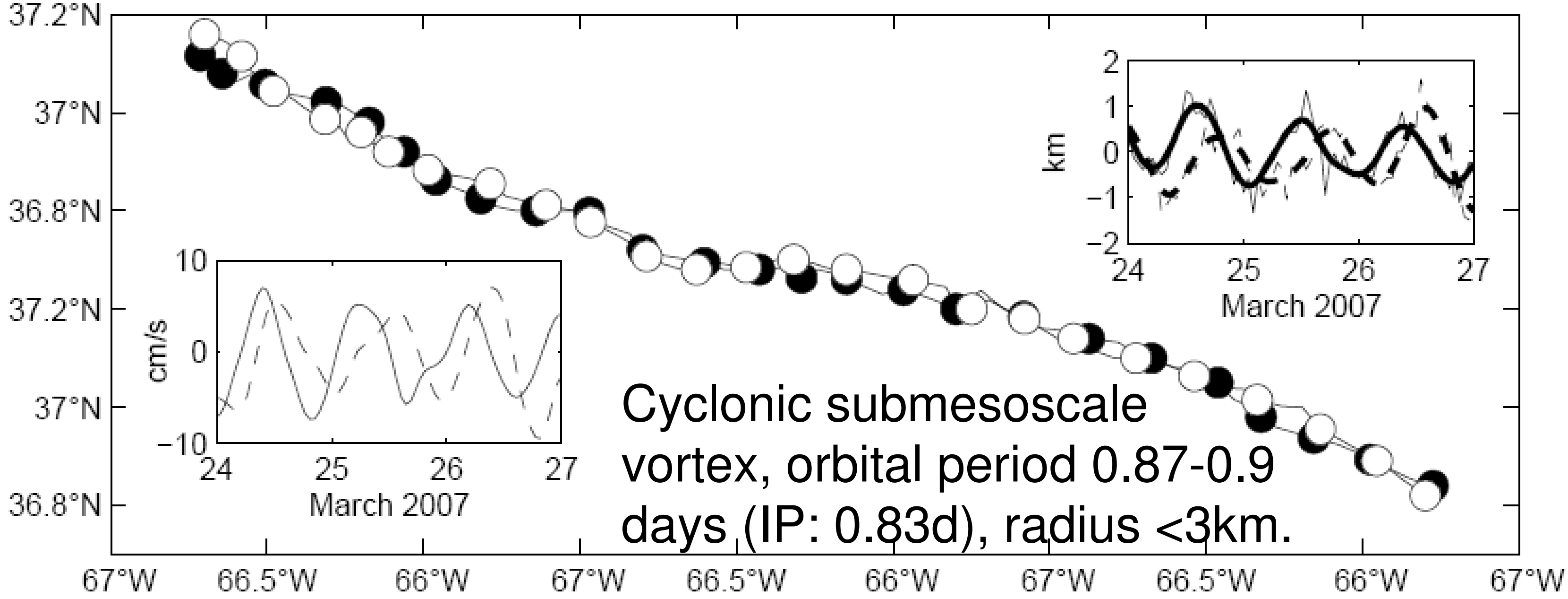
Beta-plume dynamics?

Rectification of undersampled eddies? (c.f. Schlax and Chelton, 2008)

Submesocale motion

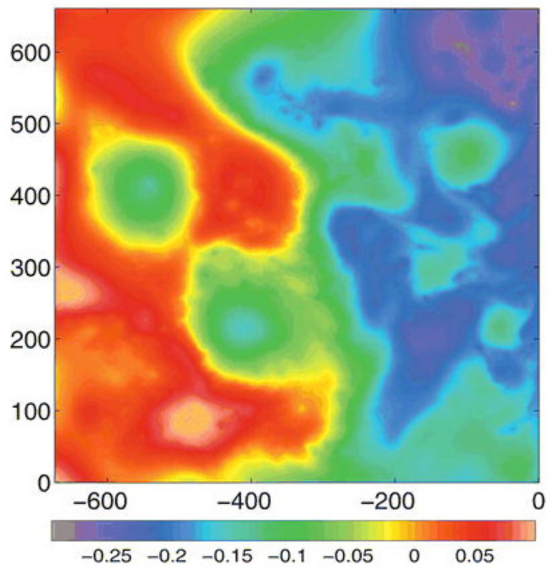






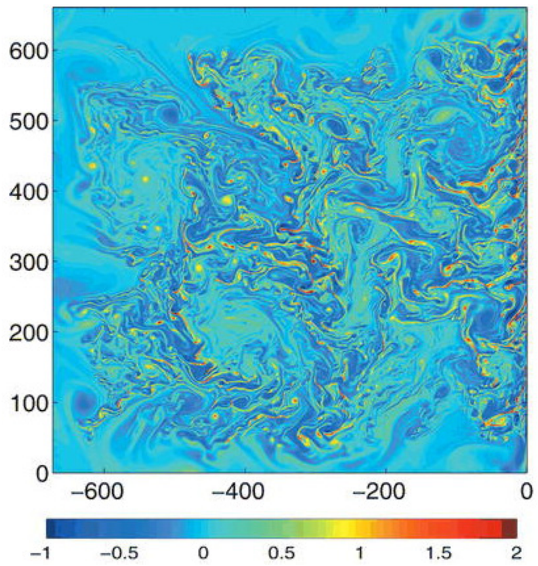
Cyclonic submesoscale vortex, orbital period 0.87-0.9 days (IP: 0.83d), radius <3km.

How important is the submesoscale?



Left: sea height (m) in a 0.75km-resolution simulation. Low R_o mesoscale vortices dominate.

Right: concurrent surface vorticity (scaled by *f*). High R_o, predominantly cyclonic submesoscale vortices dominate (Capet et al, 2008).

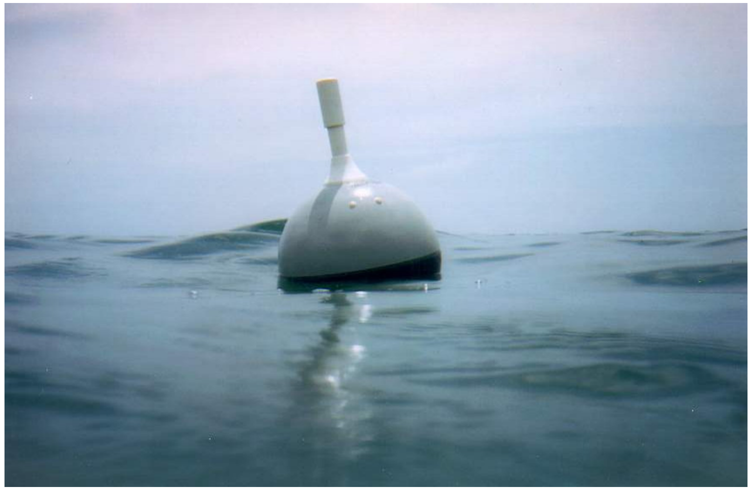


Surface Quasigeostrophic theory (*c.f.,* Blumen,. 1978; Klein et al., 2008):

- Submesoscale features associated with large vertical motion.
- Motions feed inverse energy cascade to small scales.
- Potential to flatten wavenumber spectrum at surface.

Challenge: intermittent, small (hard to observe, numerically expensive to resolve).

Surface Velocity Observations from the Global Drifter Program



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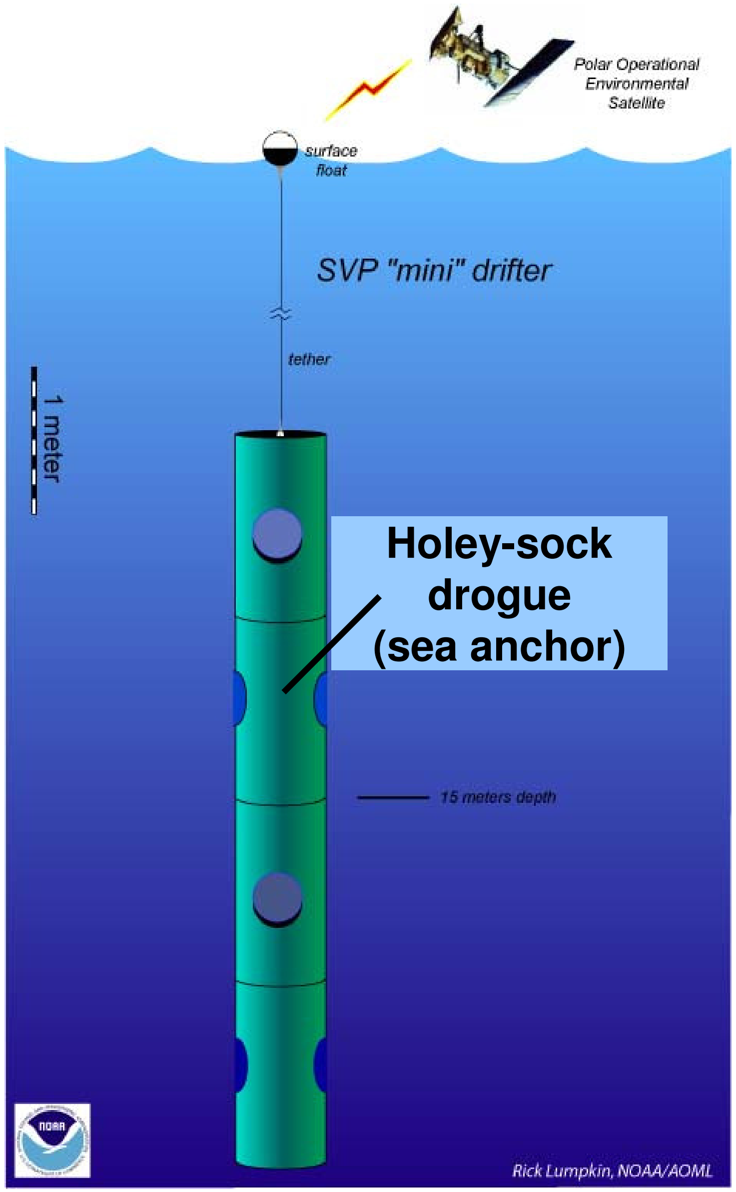
The Drifter



Spherical surface float

Polyurethane impregnated tether

Holey Sock nylon drogue centered at 15-m depth

Transmitter, D-cells batteries inside the float

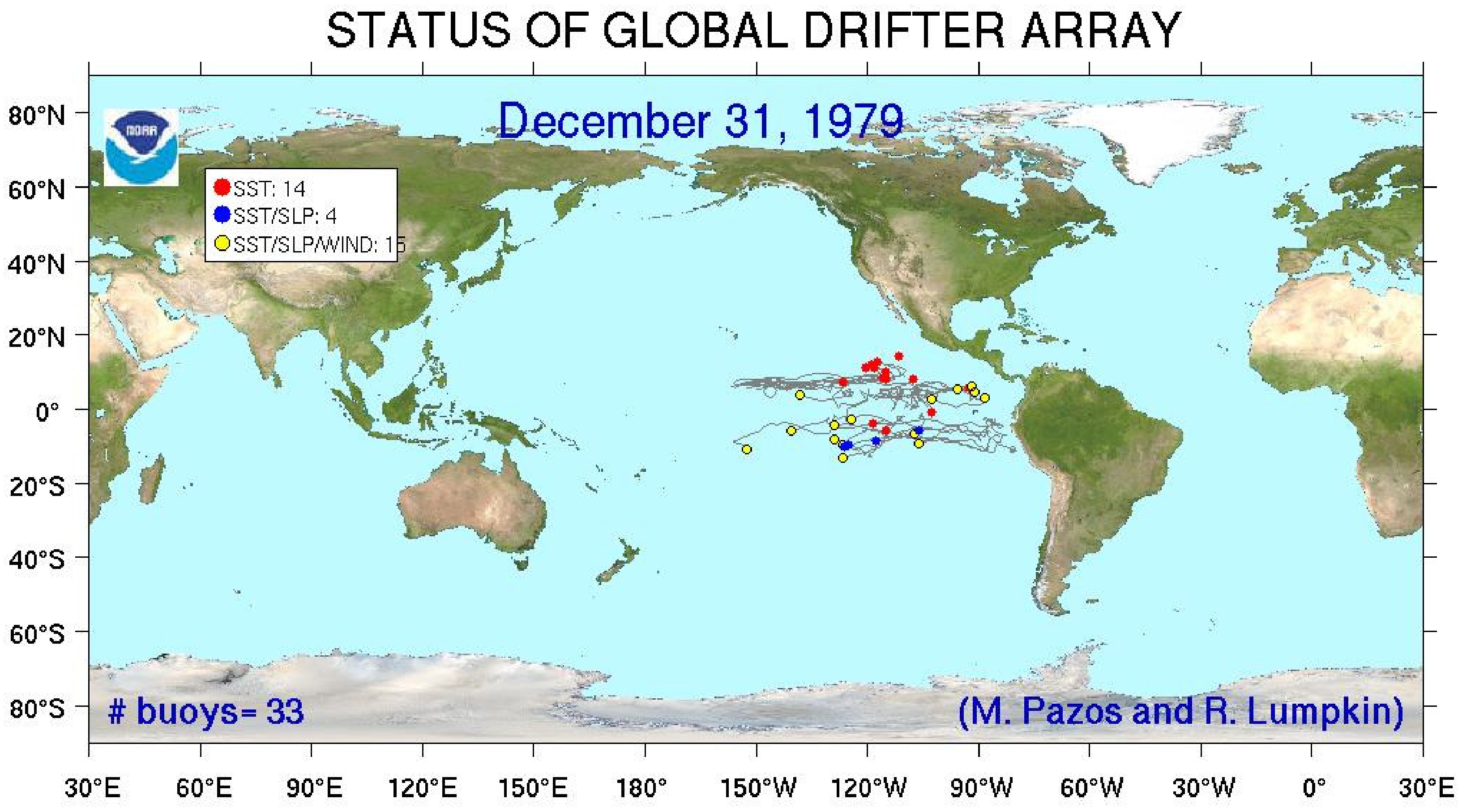
Cost: ~$1800.

Sensors:

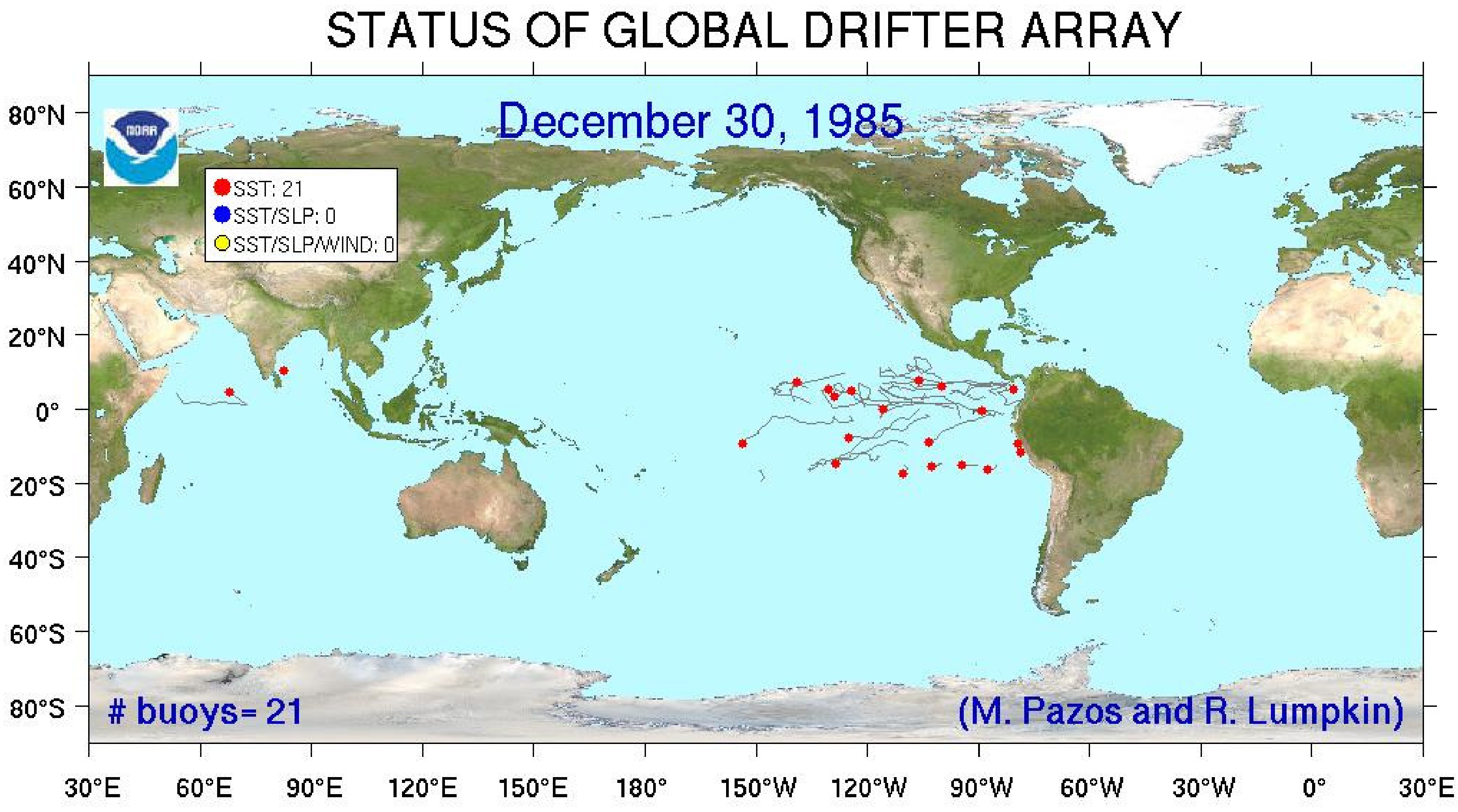
Thermistor: measures SST

Other Sensors that can be added:

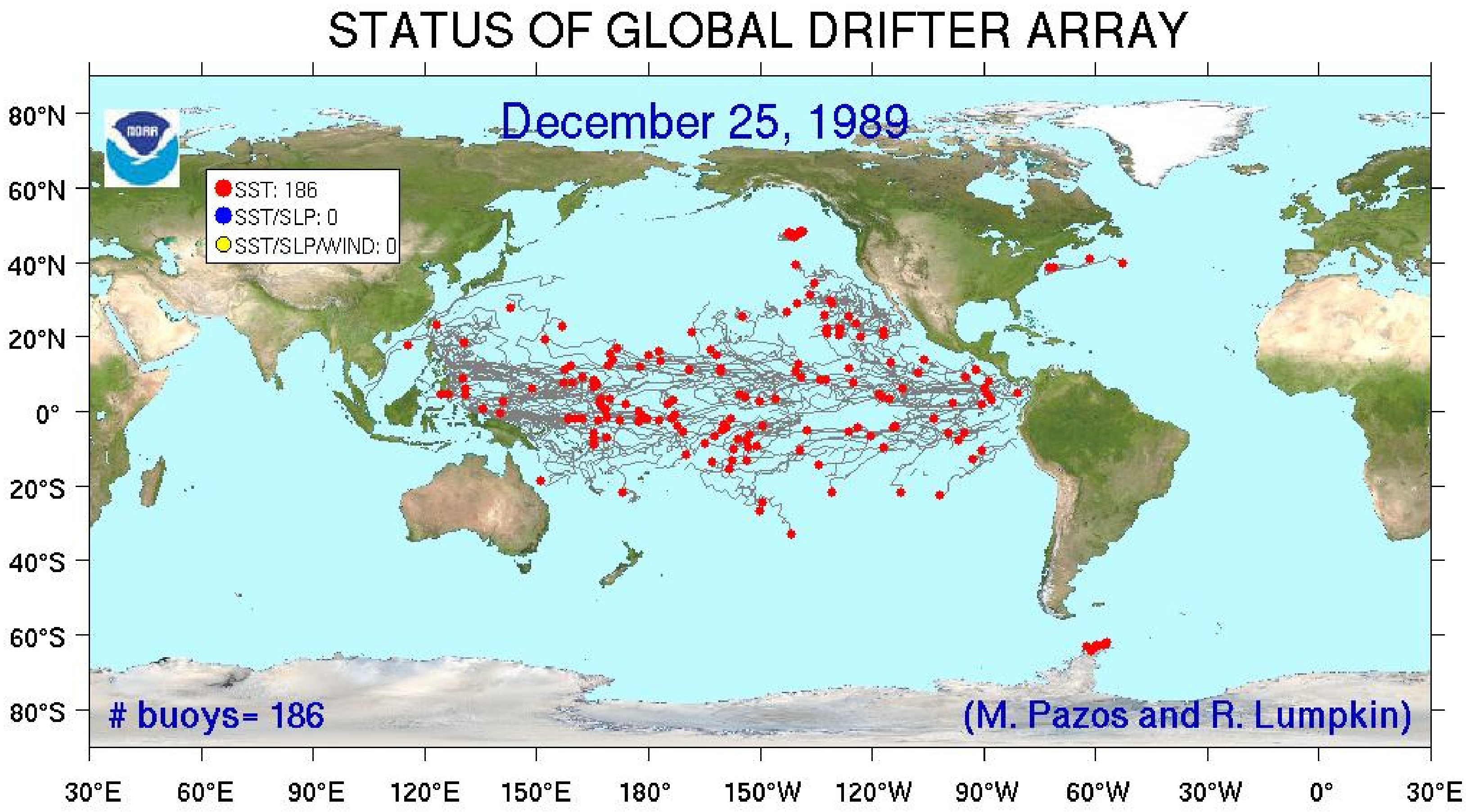
Barometric pressure, wind, subsurface temperatures, salinity



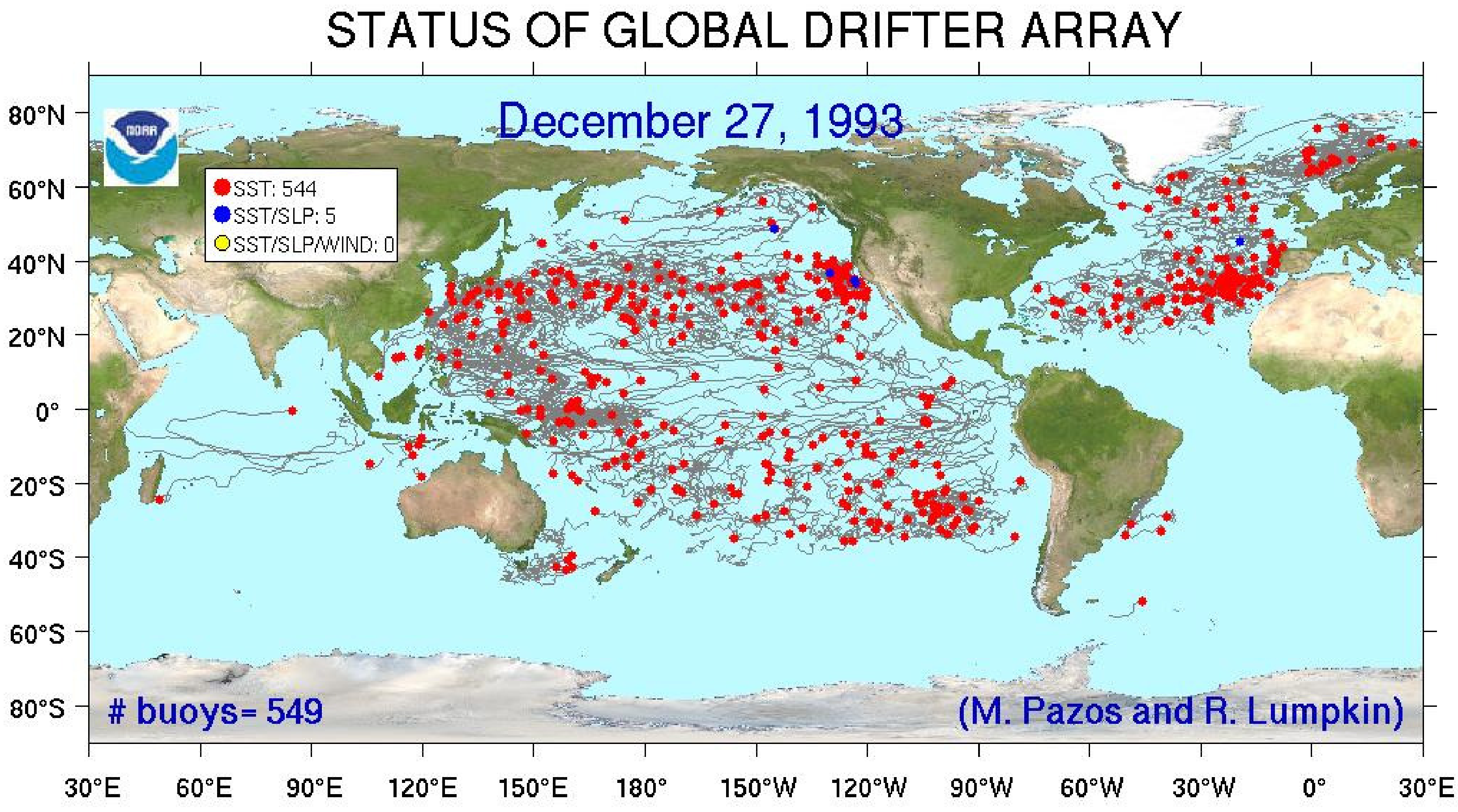
First deployments of Surface Velocity Program-type drifters as part of TOGA: ***Tropical Pacific.***



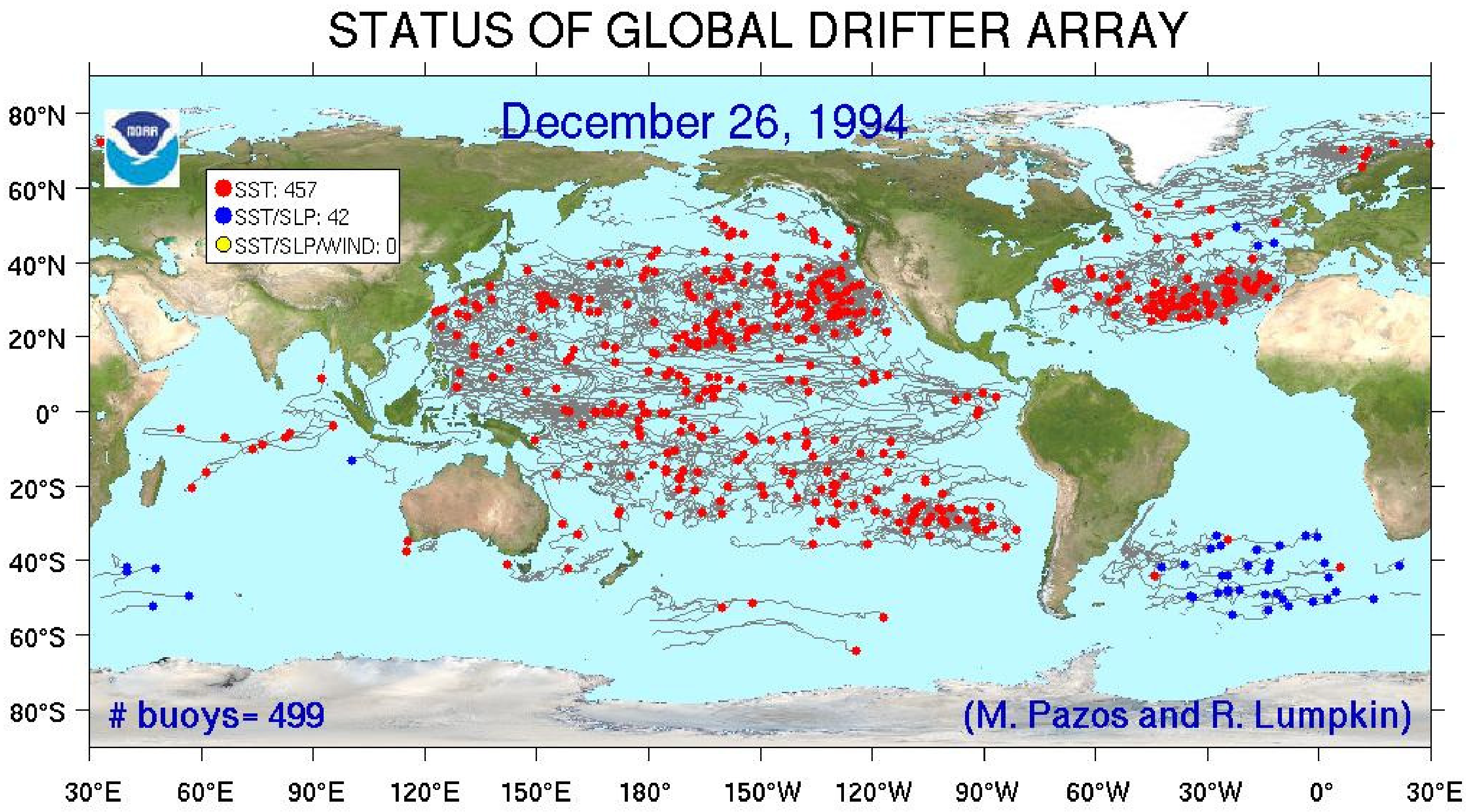
First non-tropical Pacific deployments.



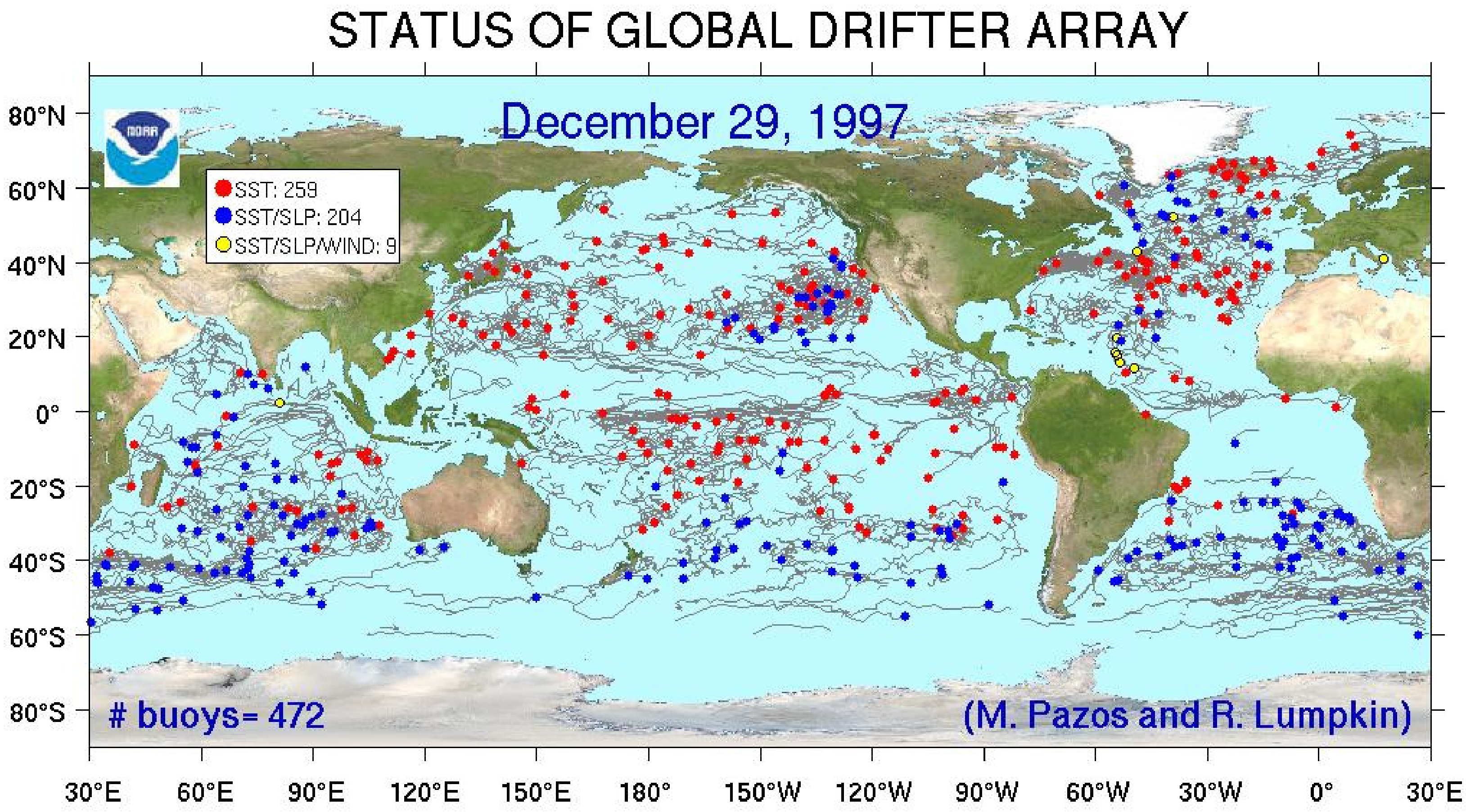
1989: start of sustained North Atlantic deployments



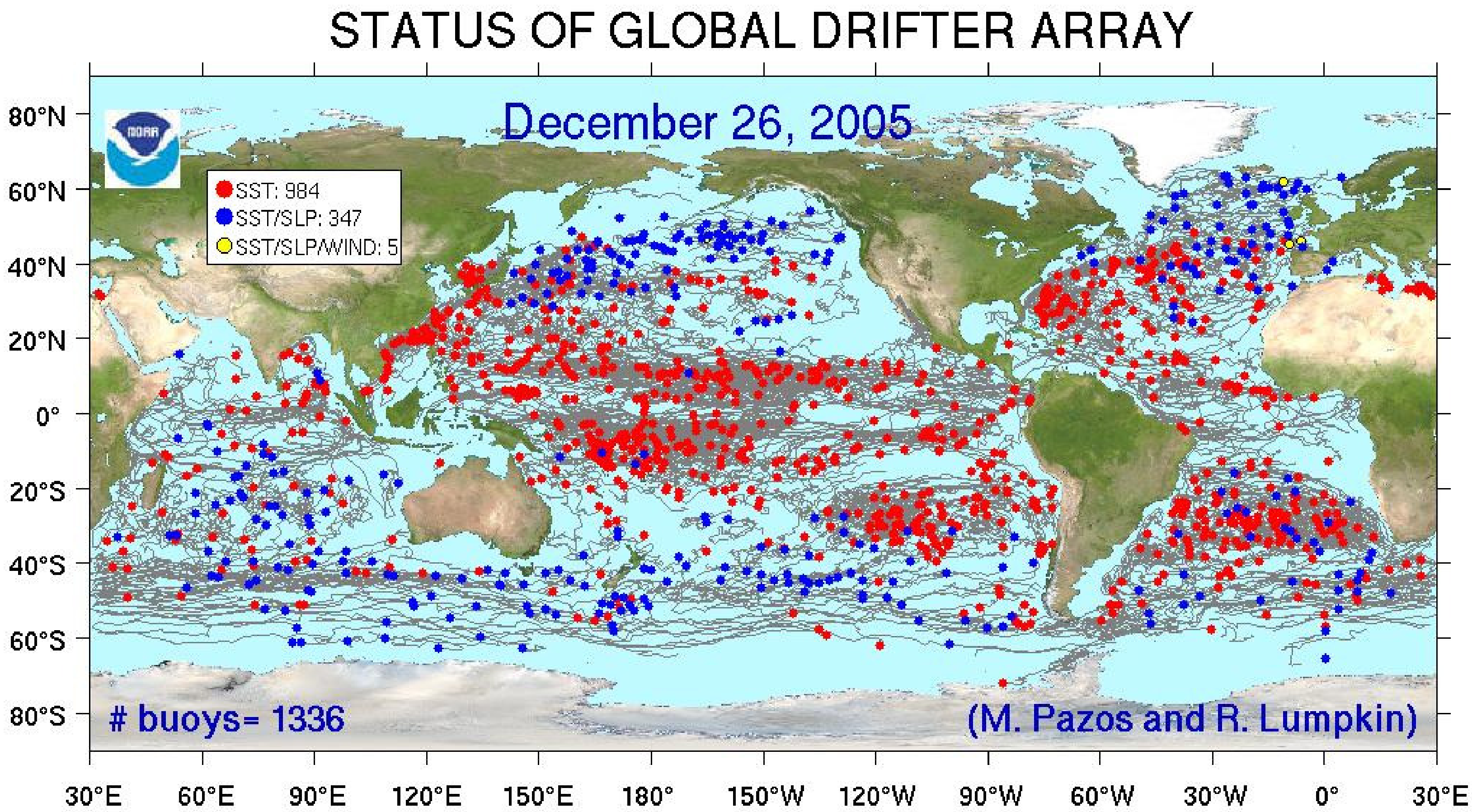
1993: start of sustained South Atlantic deployments



1994: start of sustained Indian Ocean deployments



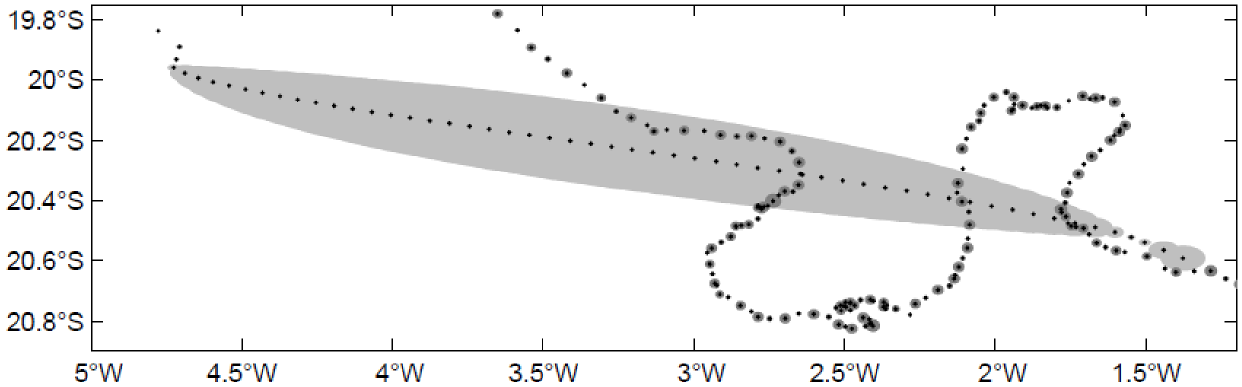
1997: start of sustained Tropical Atlantic deployments



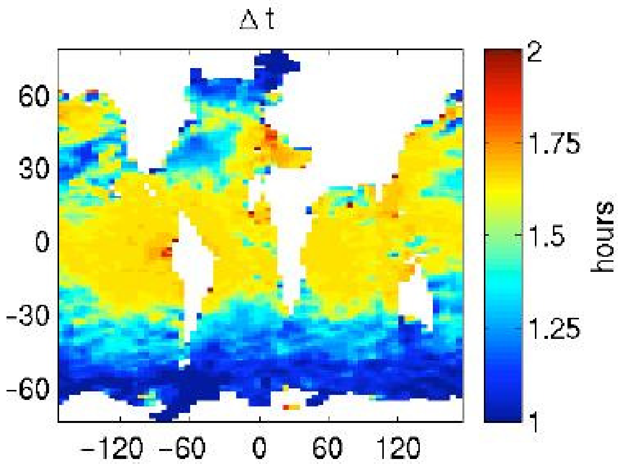
2005: GCOS goal of 1250 drifters reached in September.

Data temporal resolution

Before December 2004, position fixes acquired by two of the satellites were processed by Argos. 6–9 fixes per day.

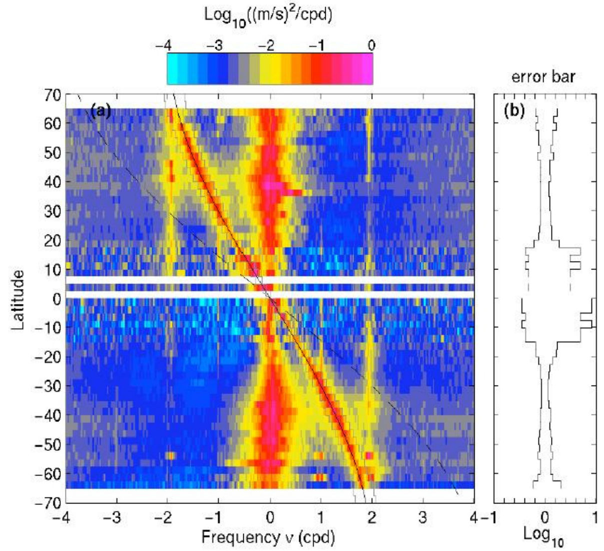


December 2004: temporal resolution increased to ~hourly.

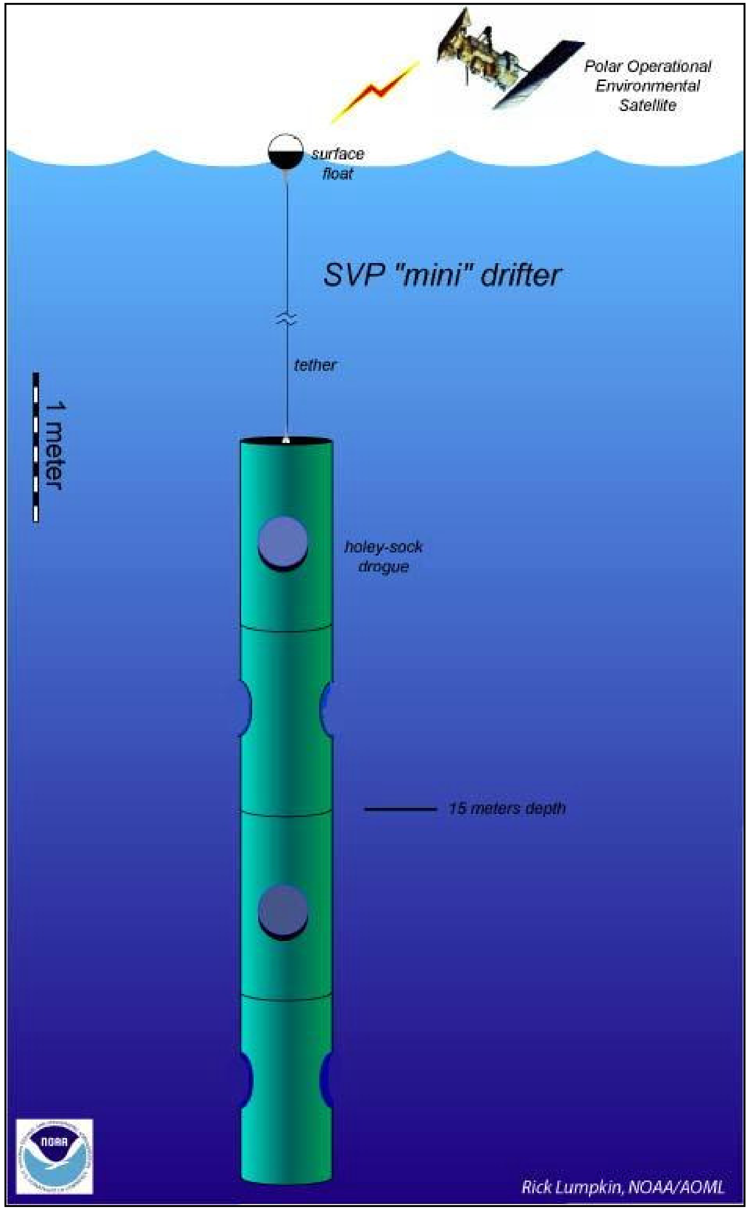


Left: resolution of drifter data since 2005.

Right: spectral distribution of energy from high resolution data (Elipot and Lumpkin, 2008).



Drifter motion:

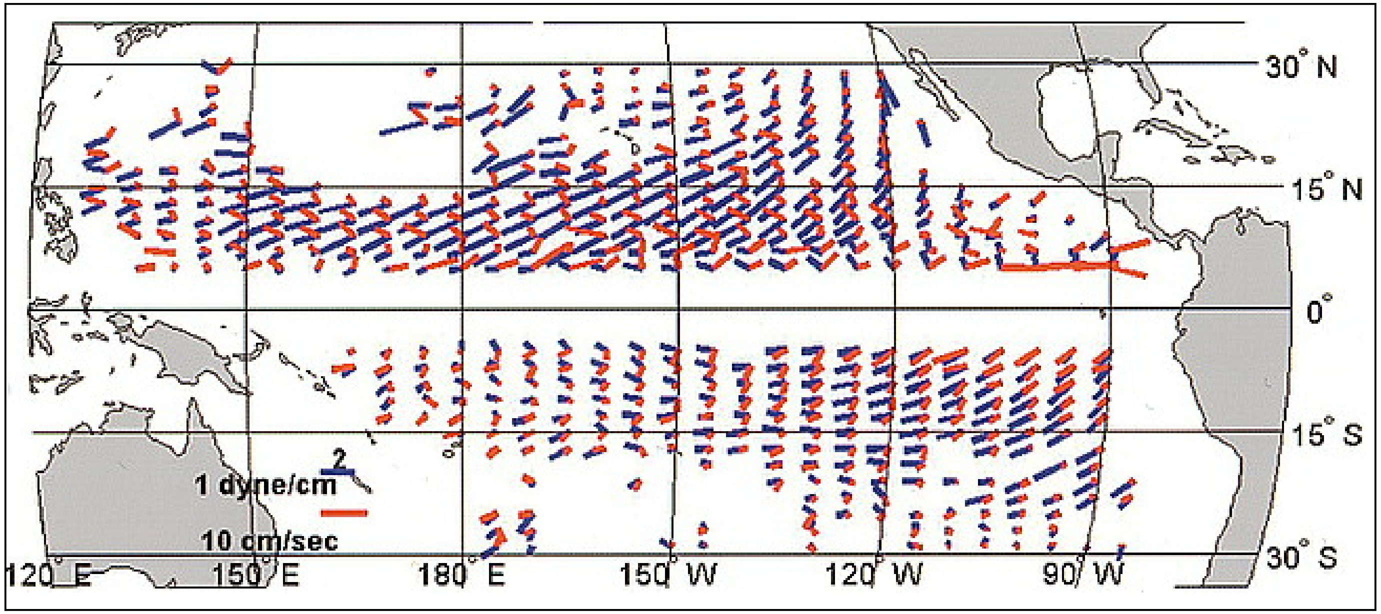


$$u = u_{Ek} + u_{geo} + u_{slip} + u_{resid}\,.$$

$$u = \boxed{u_{Ek}} + u_{geo} + u_{slip} + u_{resid}.$$

<u>Ekman</u>: Ralph and Niiler (1999), Niiler (2001).

Geostrophic mean from hydrographic climatology, variations addressed by averaging in 2°× 5° bins.



$$u_{Ek} = A\sqrt{\tau / \rho |f|}.$$

Mean angle 54° off the wind.

For NCEP winds, best fit A=0.081 $s^{-1/2}$.

$$u = u_{Ek} + \boxed{u_{geo}} + u_{slip} + u_{resid}.$$

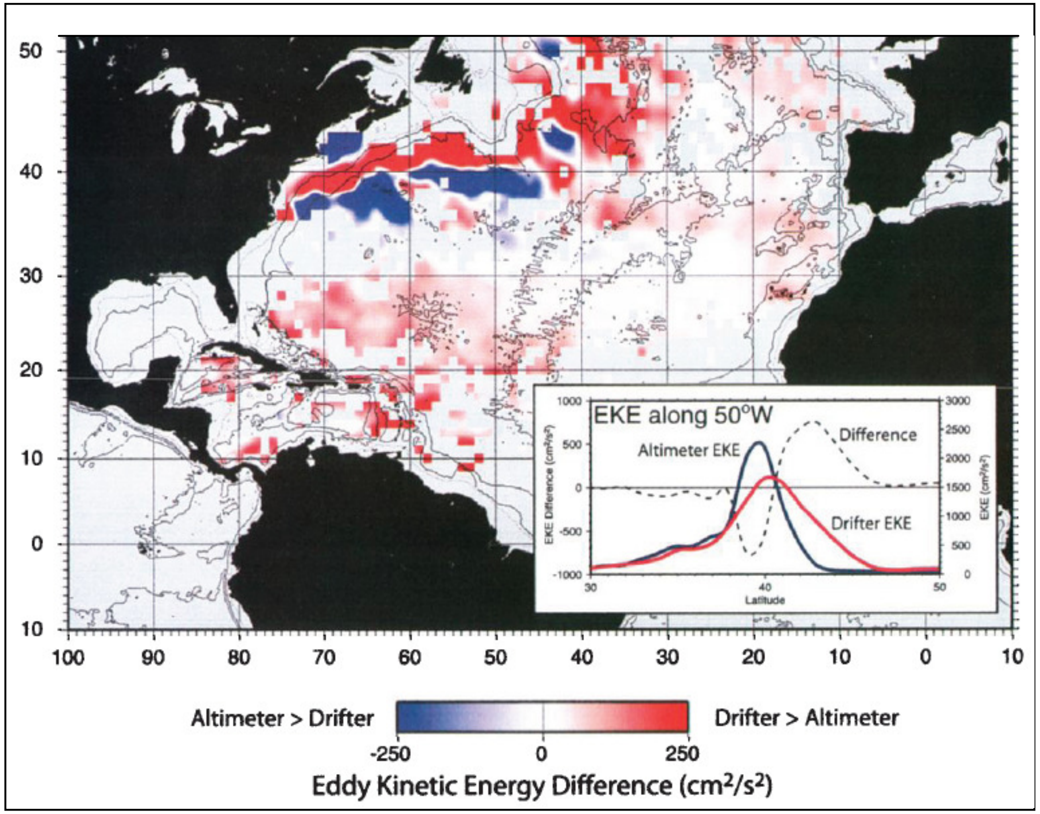
<u>Geostrophic</u>: For many studies (e.g., Rio and Hernandez, 2003),

$$u_{geo} = \bar{u} + u'_{SLA}, \quad u'_{SLA} = \frac{g \nabla \eta'}{f}.$$

u'_{SLA} can be estimated from drifter data: remove time-mean from climatology of surface currents, and the Ekman and slip components using wind products.

How does geostrophic velocity anomaly u'_{SLA} from drifters compare to u'_{SLA} from altimetry?

$$u = u_{Ek} + \boxed{u_{geo}} + u_{slip} + u_{resid}.$$

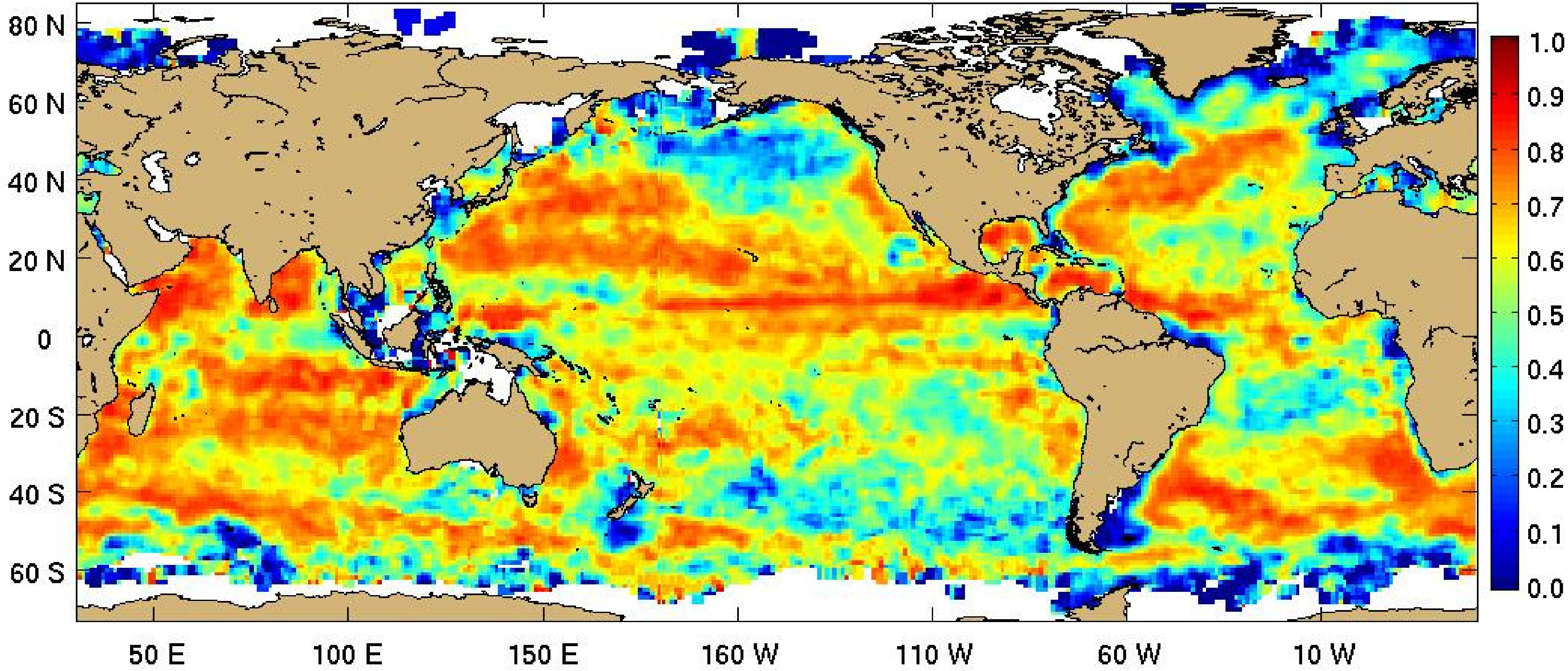


Left: Altimeter EKE minus drifter EKE (Fratantoni, 2001).

Several reasons that these can differ in general, even if Ekman and slip are perfectly removed:

- centrifugal force, submesoscale motion, etc.
- mismatch between spatial smoothing of altimetry, temporal smoothing of drifters, and energy spectra of motion.

Correlation coefficient, drifter/altimetry u'_{SLA}



(drifter velocities lowpassed at 5 days)

>0.7: more than half of low frequency variance captured in altimetry.

$$u = u_{Ek} + u_{geo} + \boxed{u_{slip}} + u_{resid}.$$

With drogue:

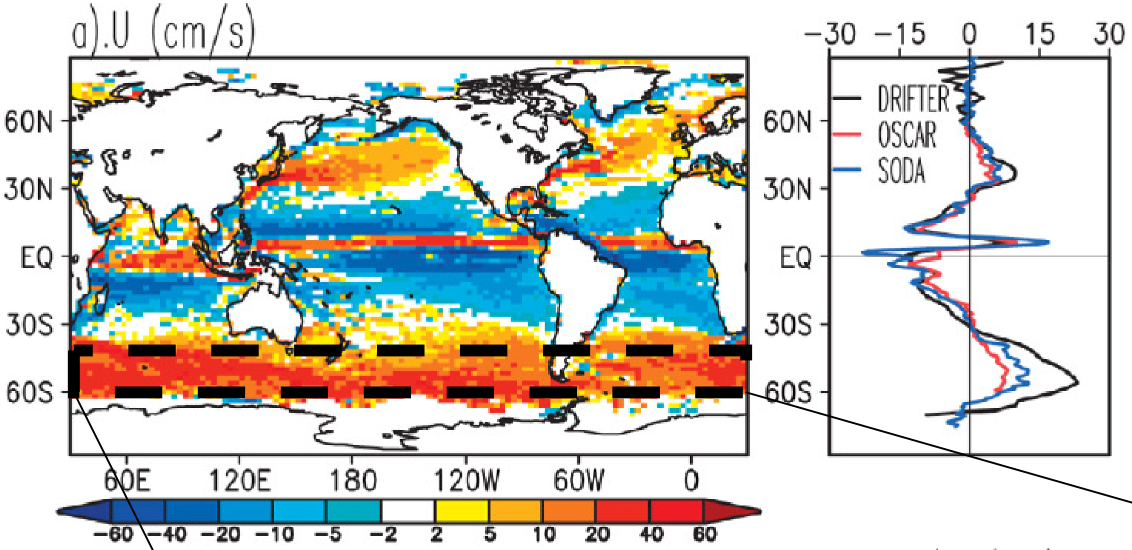
downwind slip: 0.7 cm/s per 10 m/s of wind (Niiler and Paduan, 1995, Niiler et al., 1999).

Drogue lost:

8.6±0.7 cm/s per 10 m/s wind (Pazan and Niiler, 2001).

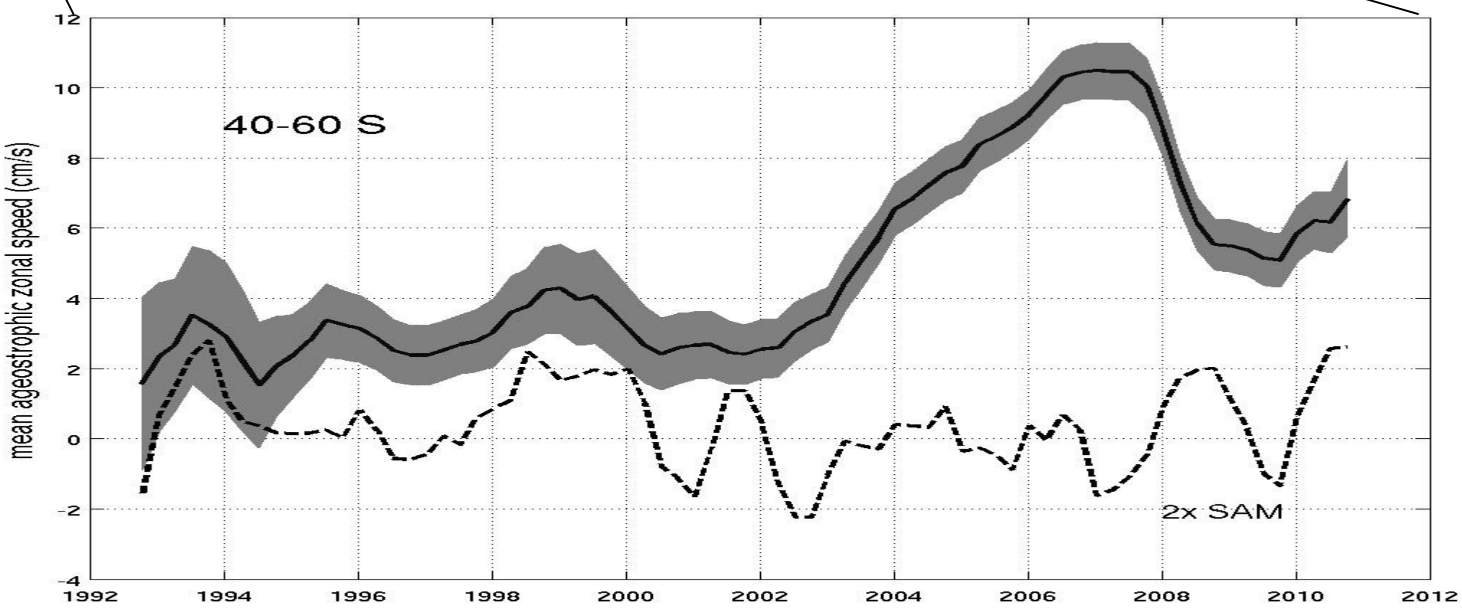
Slip has not been measured at >10 m/s wind.

Evidence of problems



Left: time-mean zonal currents from drifters and two independent analyses (Grodsky *et al*., 2011).

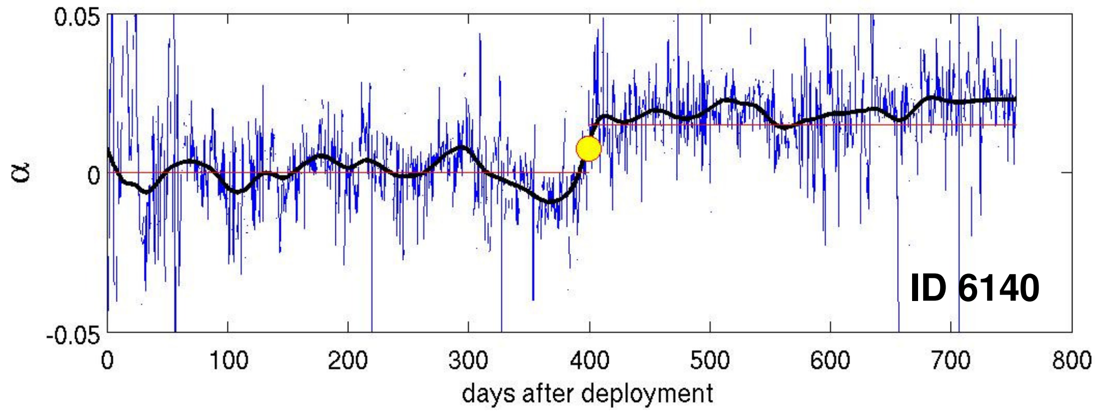
Geostrophic component can be calculated from AVISO and CLS mean dynamic height (Rio *et al*.., 2011).



Drogue presence reanalysis

Follows methodology suggested by M-H. Rio. (*Talk in Session 4*)

Determine when α (residual downwind motion) increases for each drifter.



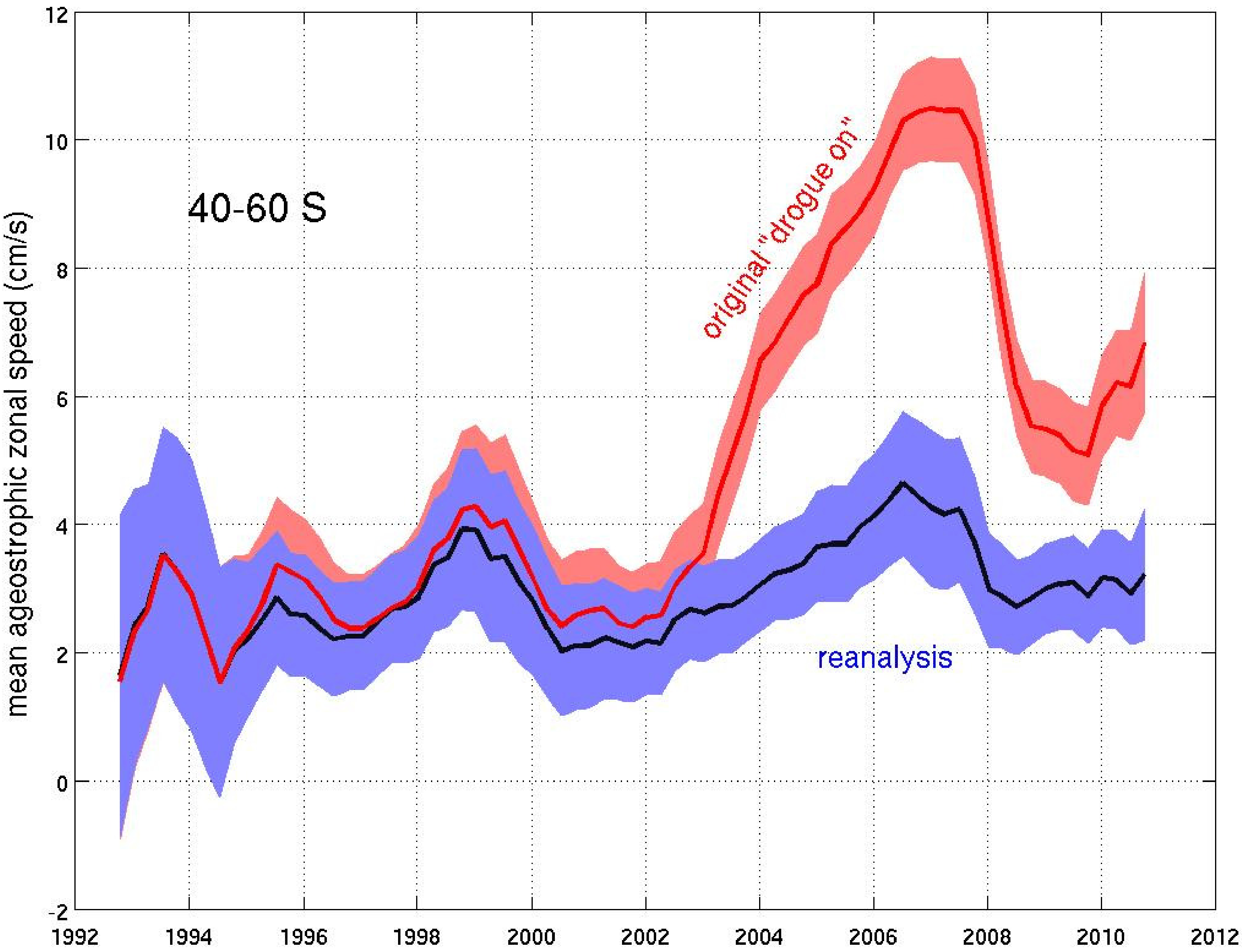
Results: 8.7k of 13.6k drifters (64%) : < 30d difference.

α method failed to identify 2055 known drogue loses.

2848 drifters (21%) have drogue off date earlier by >30 days. 18% reduction in "drogue on" data for period Oct 1992—Dec 2010.

"Signal" in some submergence records that can be reinterpreted.

Drogue presence reanalysis



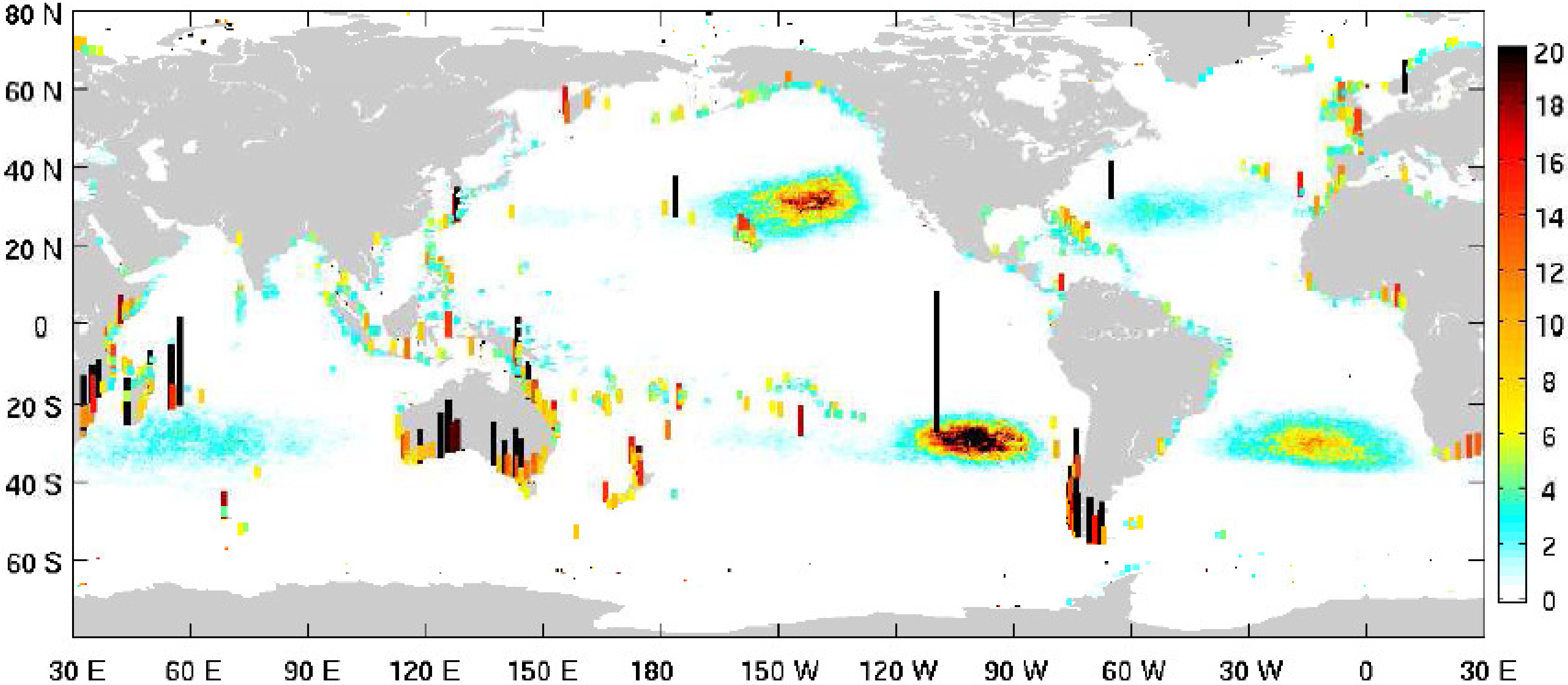
Applications

Floating marine debris

Strategy:

- Divide world's oceans into small boxes.
- For each box, find all the drifters that were ever in the box.
- Calculate where each of those drifters went five days later.
- Assume that those statistics will also describe how marine debris will be carried by ocean currents and winds.
- Use these statistics to simulate the spread of hundreds, thousands or millions of particles.

Exposure to marine debris



Distribution of the concentration of floating marine debris in arbitrary units, 10 years after being released homogeneously at a concentration of 1. Vertical bars indicate the concentration of material that has washed ashore, with color corresponding to 10X the value in the color bar.

Lumpkin et al. (2011)

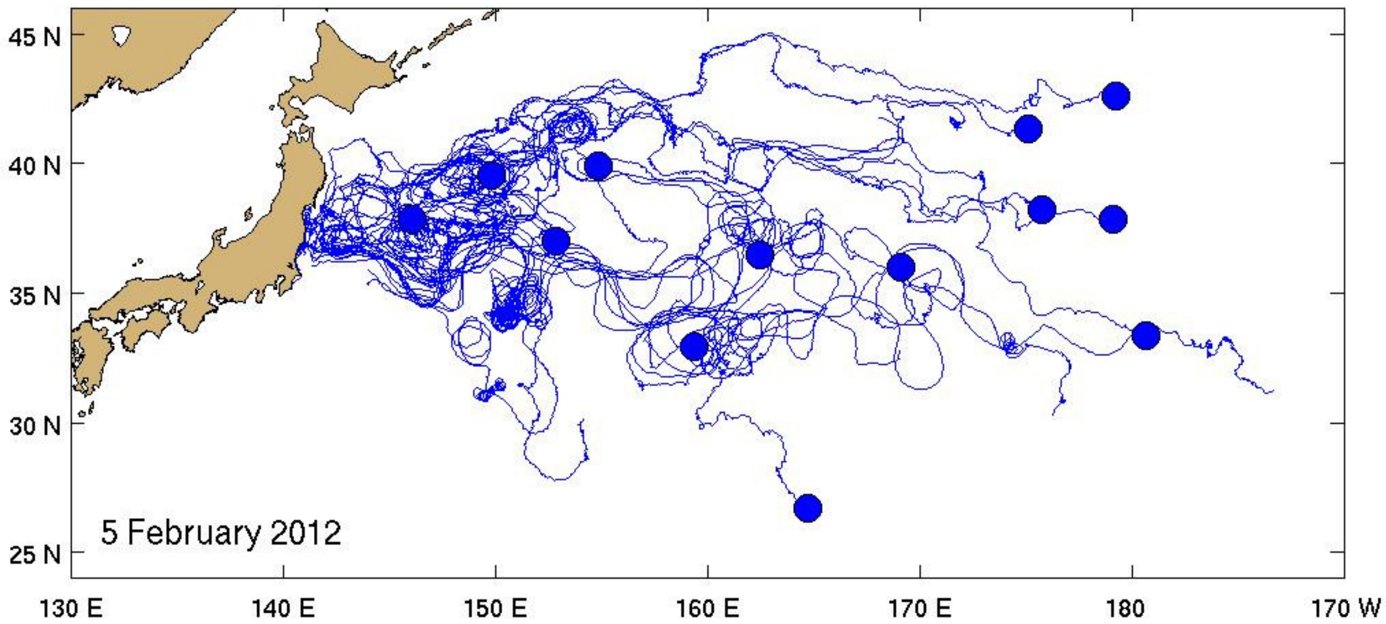
Fate of tsunami debris

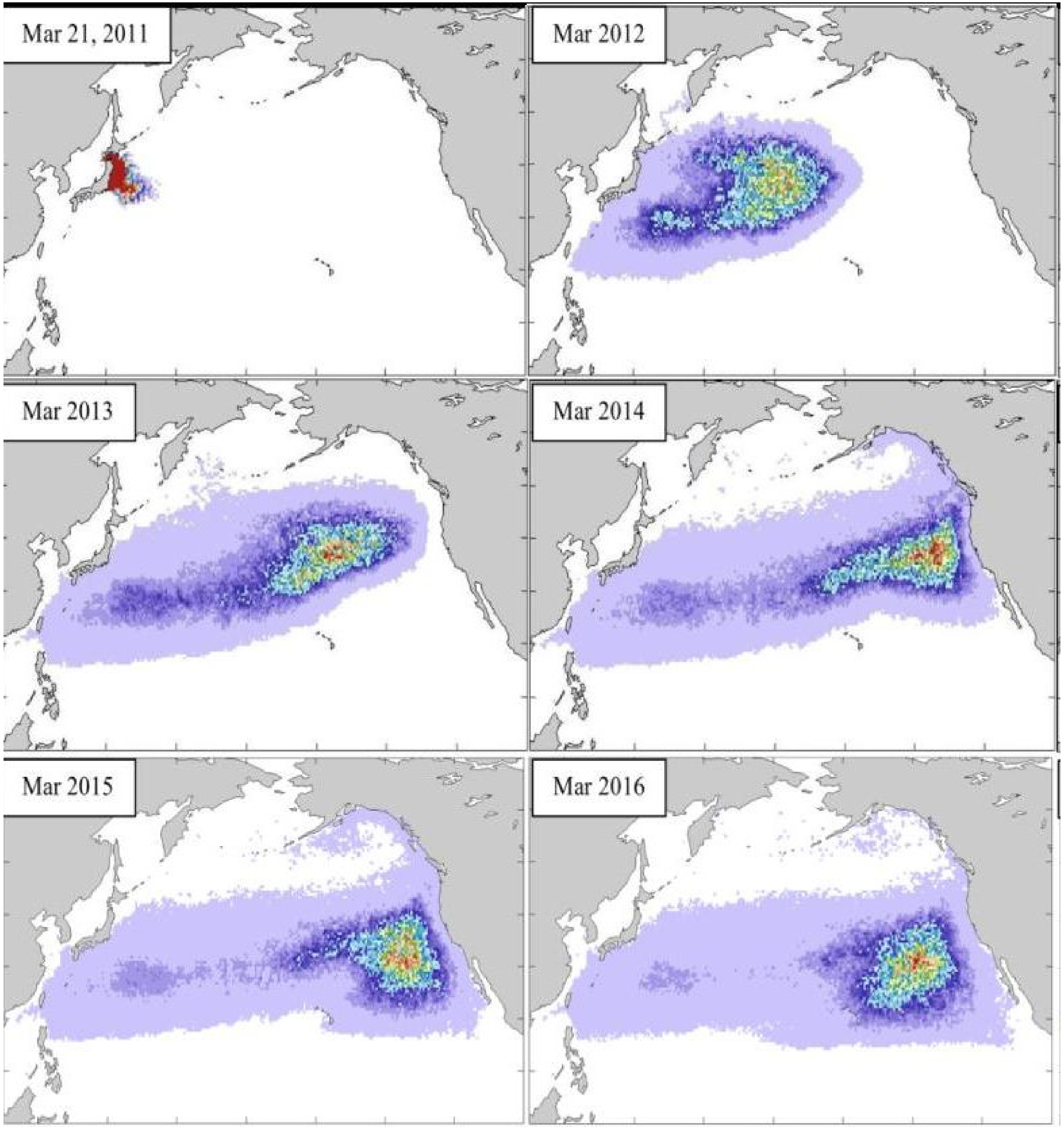
Tsunami: March 11, 2011.

Array of 36 drifters deployed: 24 in June , 12 in August.

As of Feb 2012, array spans area 26.6—42.8°N, 146°E—173°W.

Observations can be used to improve statistical and dynamical models of debris field evolution.





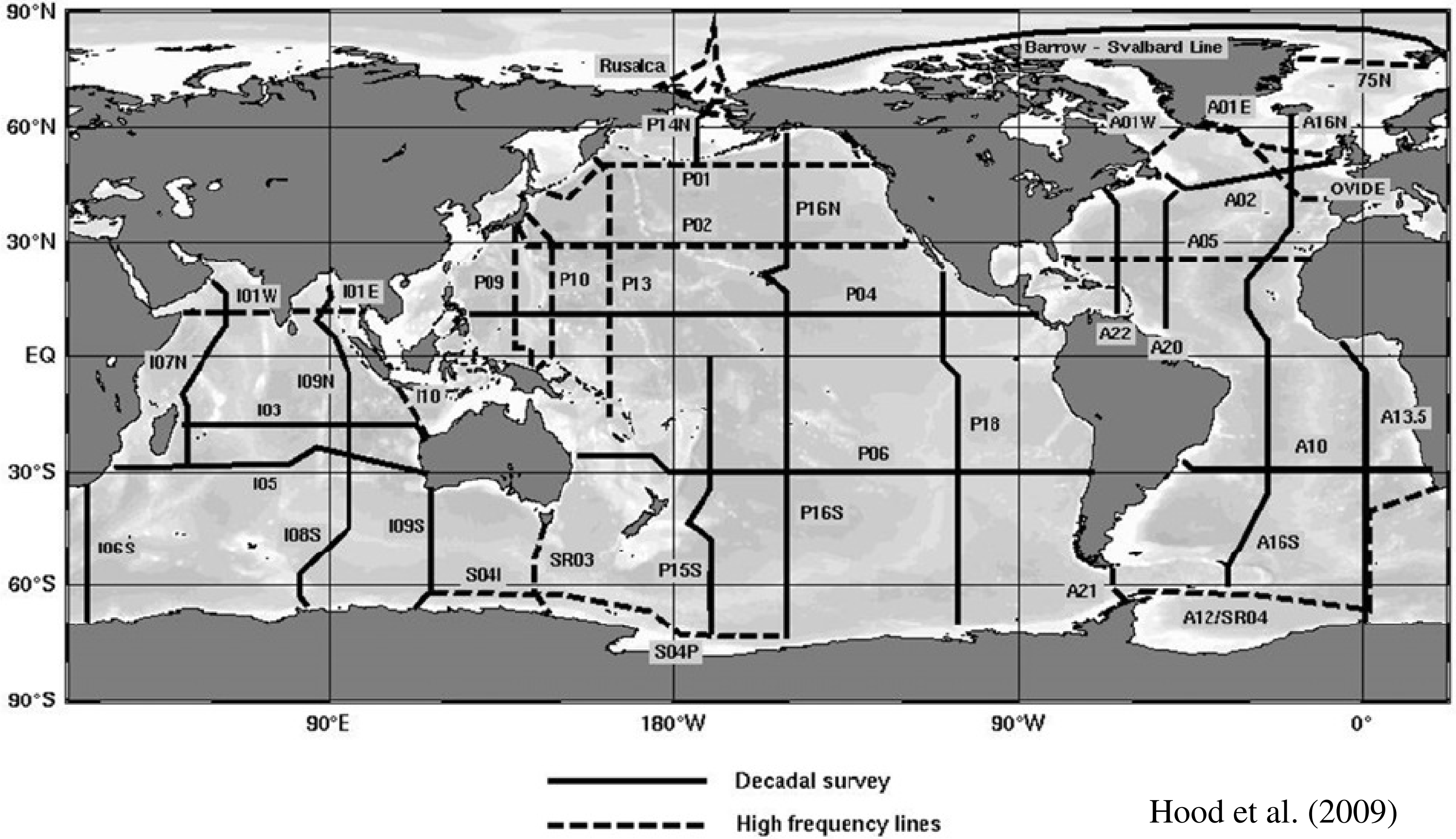
Simulations by Nikolai Maximenko and Jan Hafner (Univ. Hawaii): drifter statistics used to estimate fate of debris from 11 March 2011 earthquake and tsunami.

Other in-situ current observations

Repeat hydrography

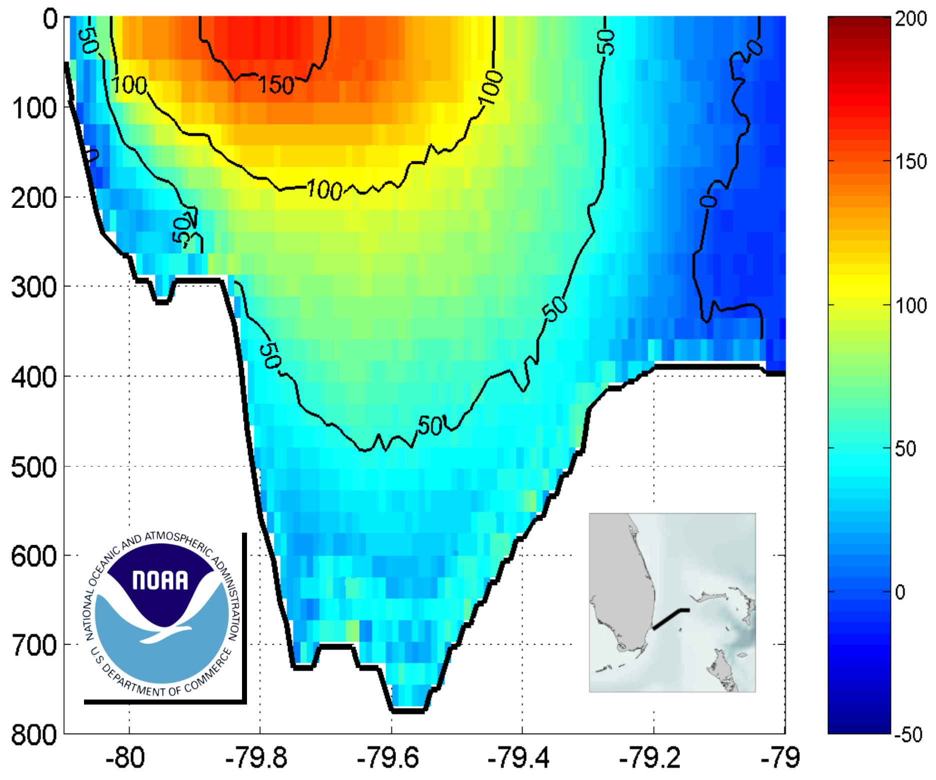
GEOSECS, WOCE/JGOFS, CLIVAR, GO-SHIP.

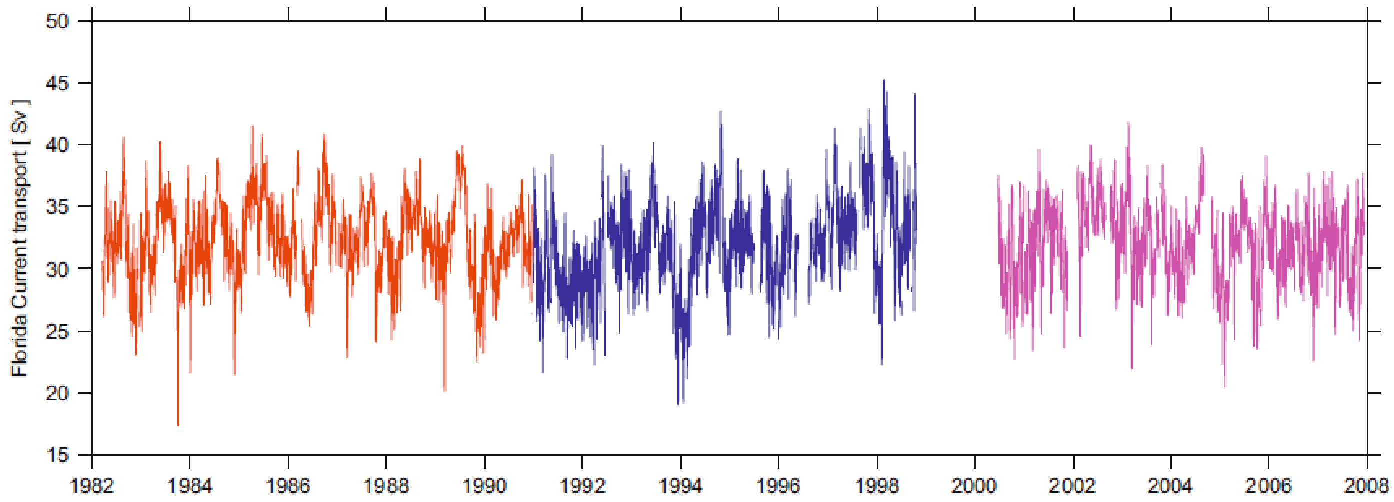
Thermal wind (geostrophic currents), usually accompanied by ADCP.



Hood et al. (2009)

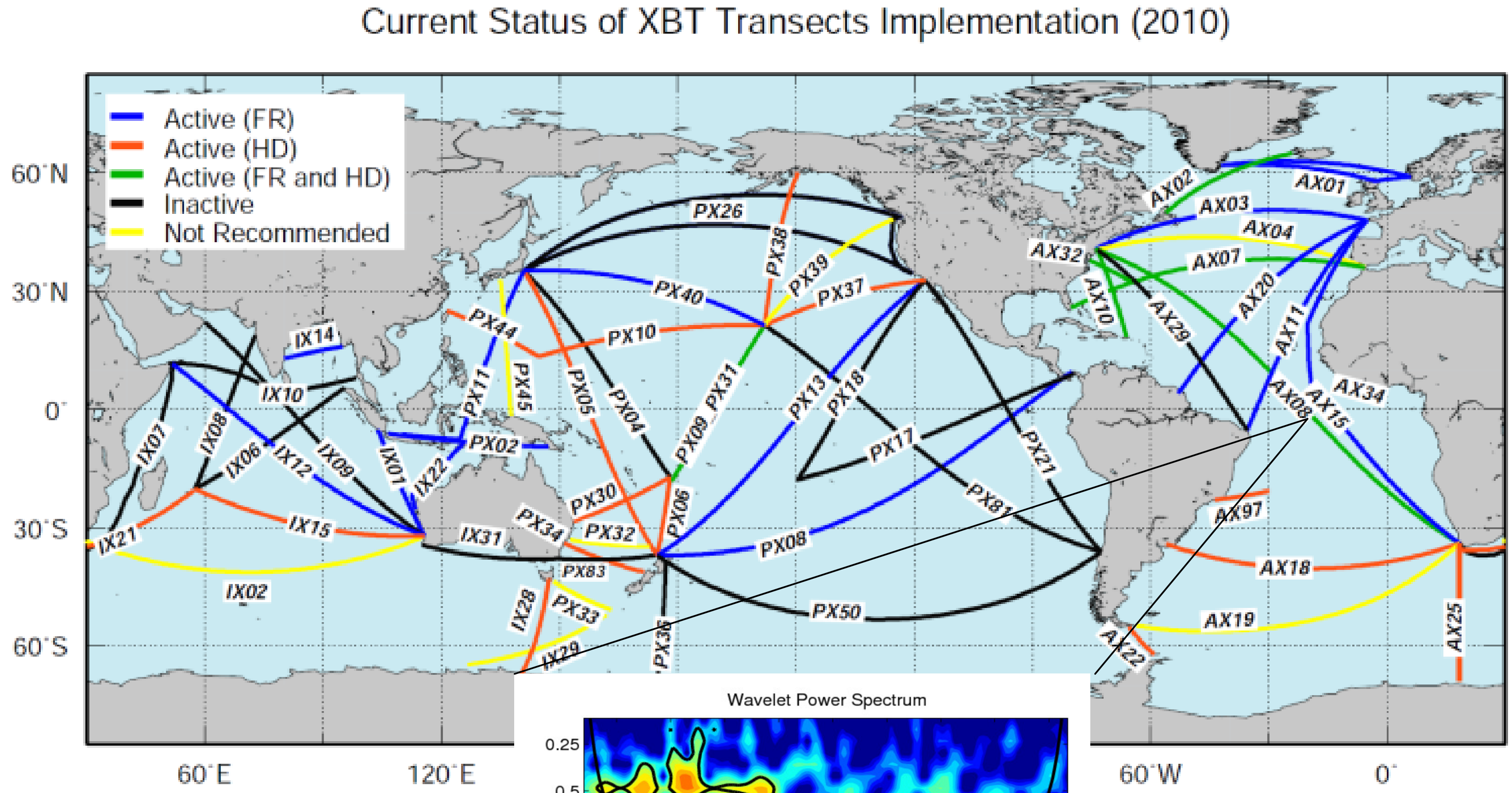
Florida Current transport: calculated by voltage on telephone cables.

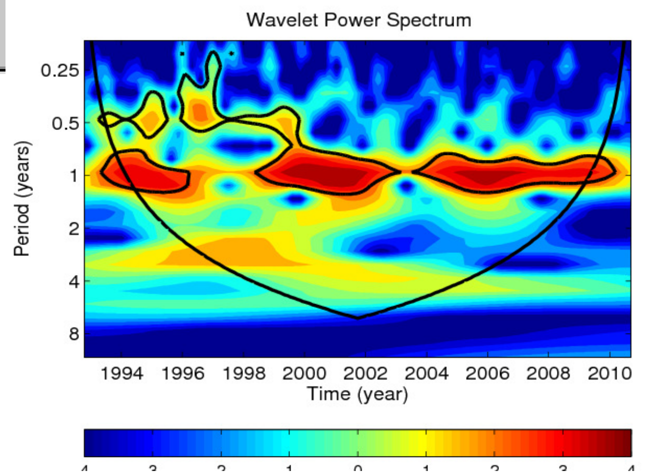




Meinen et al. (2010)

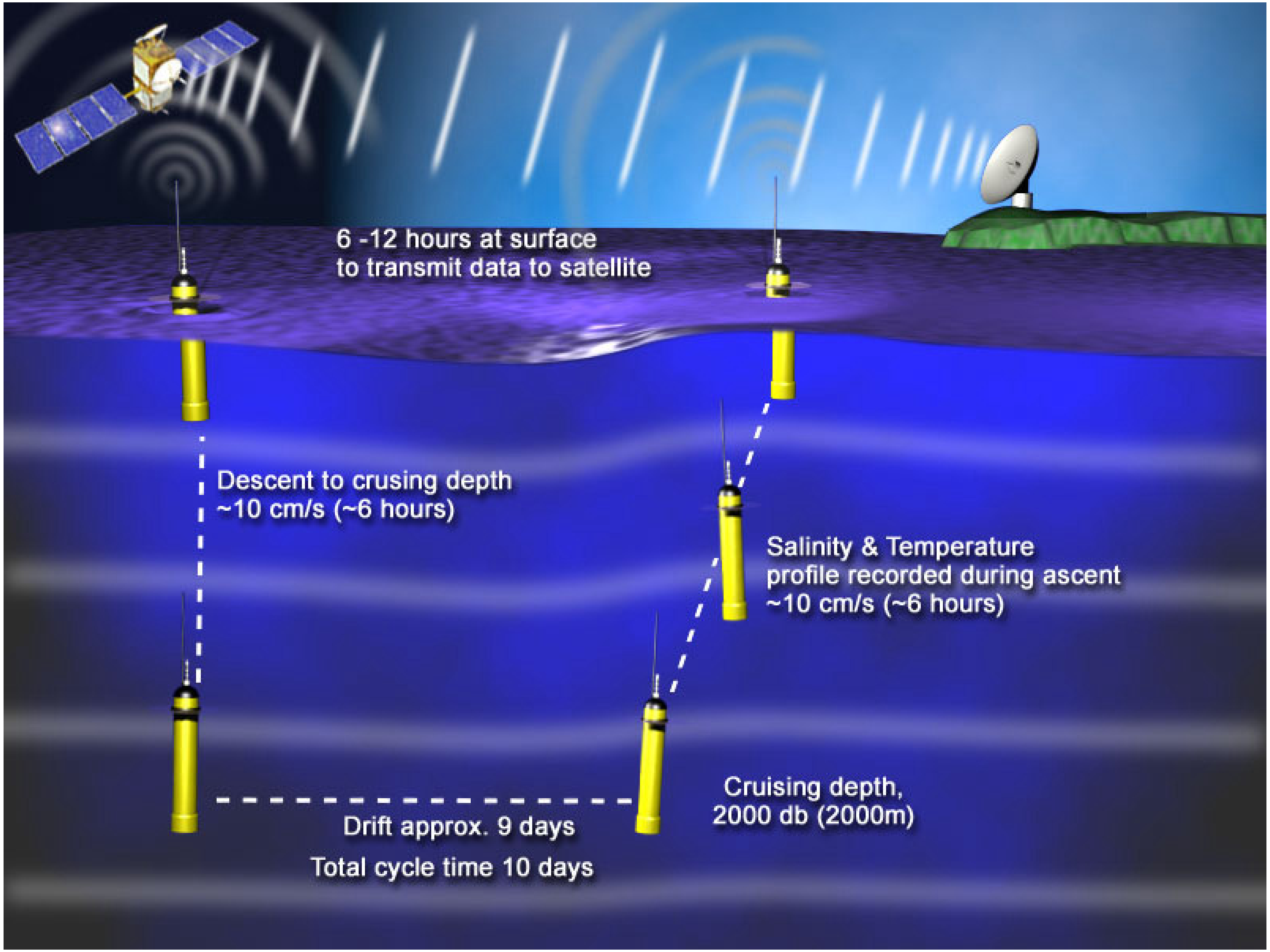
XBTs (expendable bathythermographs)



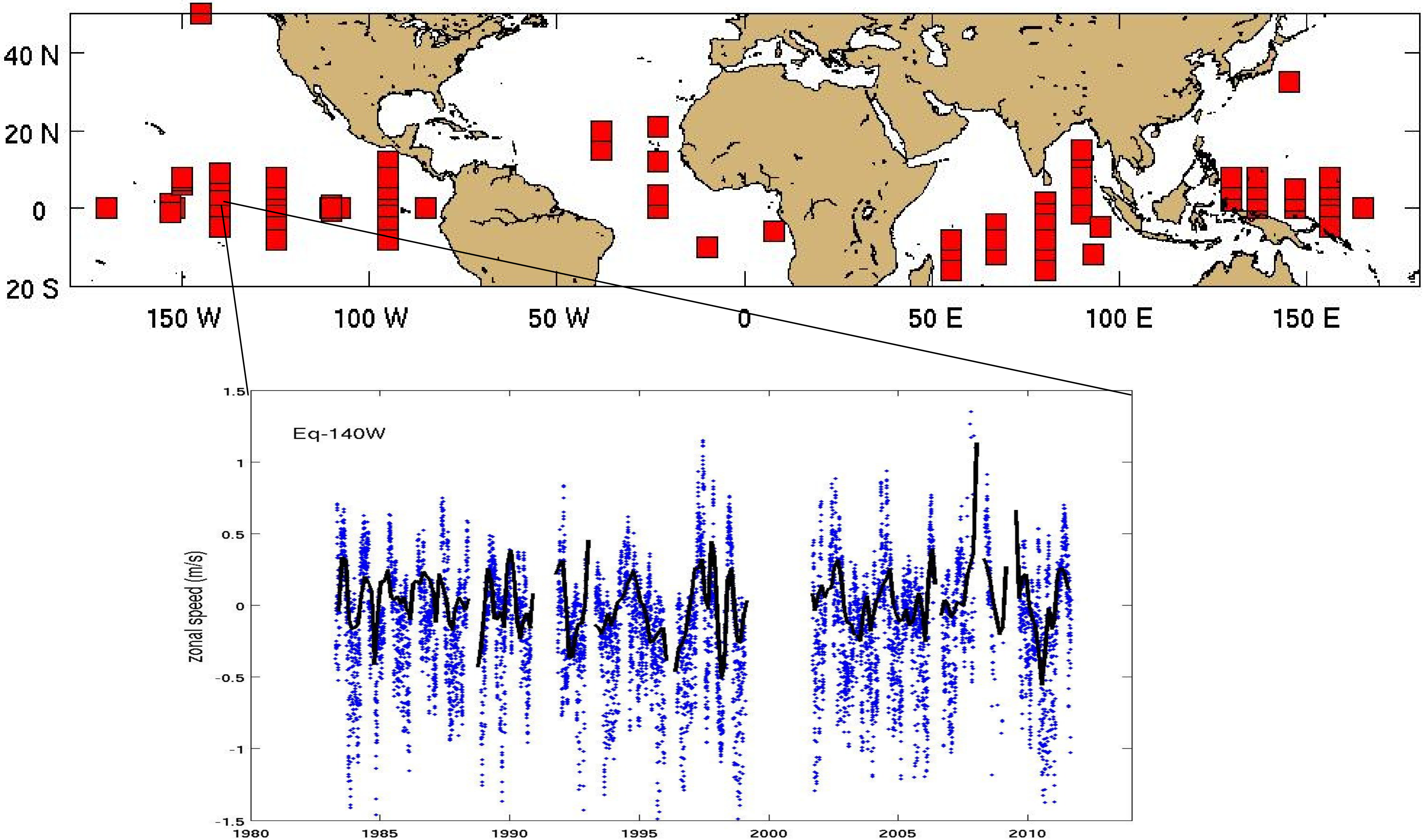


NEUC transport variability (Goes et al., 2012)

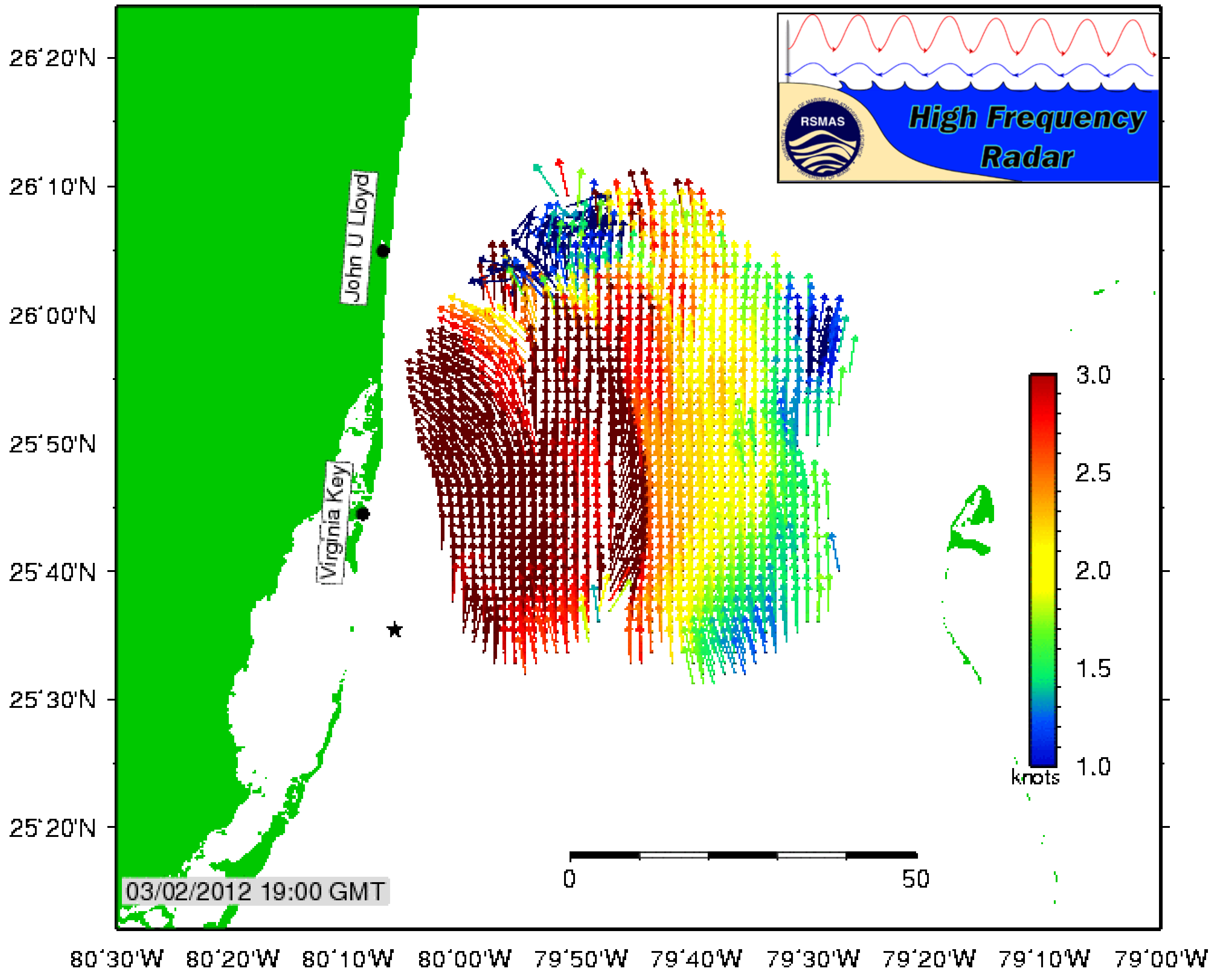
Profiling Argo floats

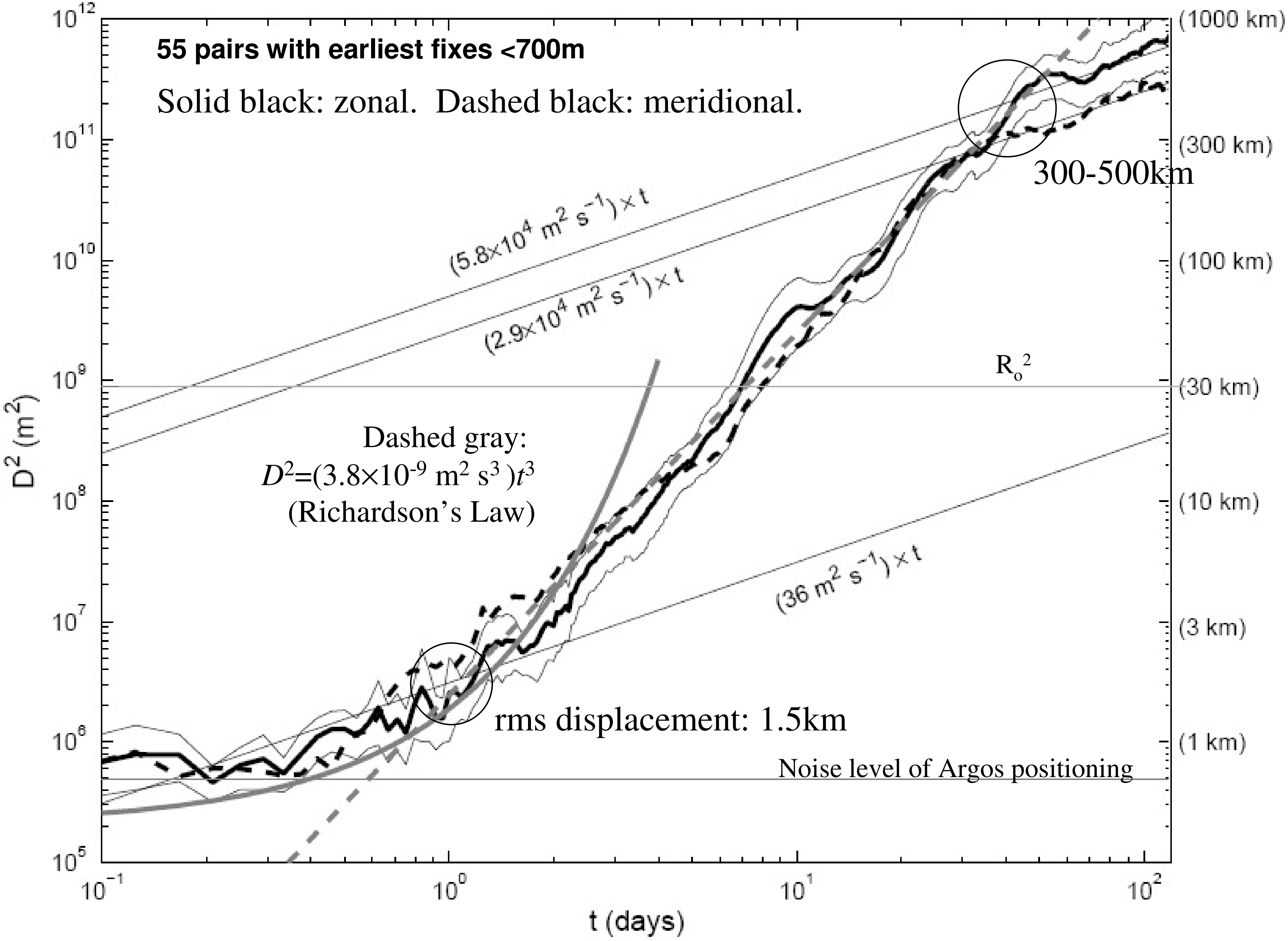


Moored current meters



Coastal radar





55 pairs with earliest fixes <700m
Solid black: zonal. Dashed black: meridional.
(5.8×10^4 m^2 s^-1)×t
(2.9×10^4 m^2 s^-1)×t
300-500km
R_o^2
Dashed gray:
D^2=(3.8×10^-9 m^2 s^3)t^3
(Richardson's Law)
(36 m^2 s^-1)×t
rms displacement: 1.5km
Noise level of Argos positioning
D^2 (m^2)
t (days)
(1000 km)
(300 km)
(100 km)
(30 km)
(10 km)
(3 km)
(1 km)