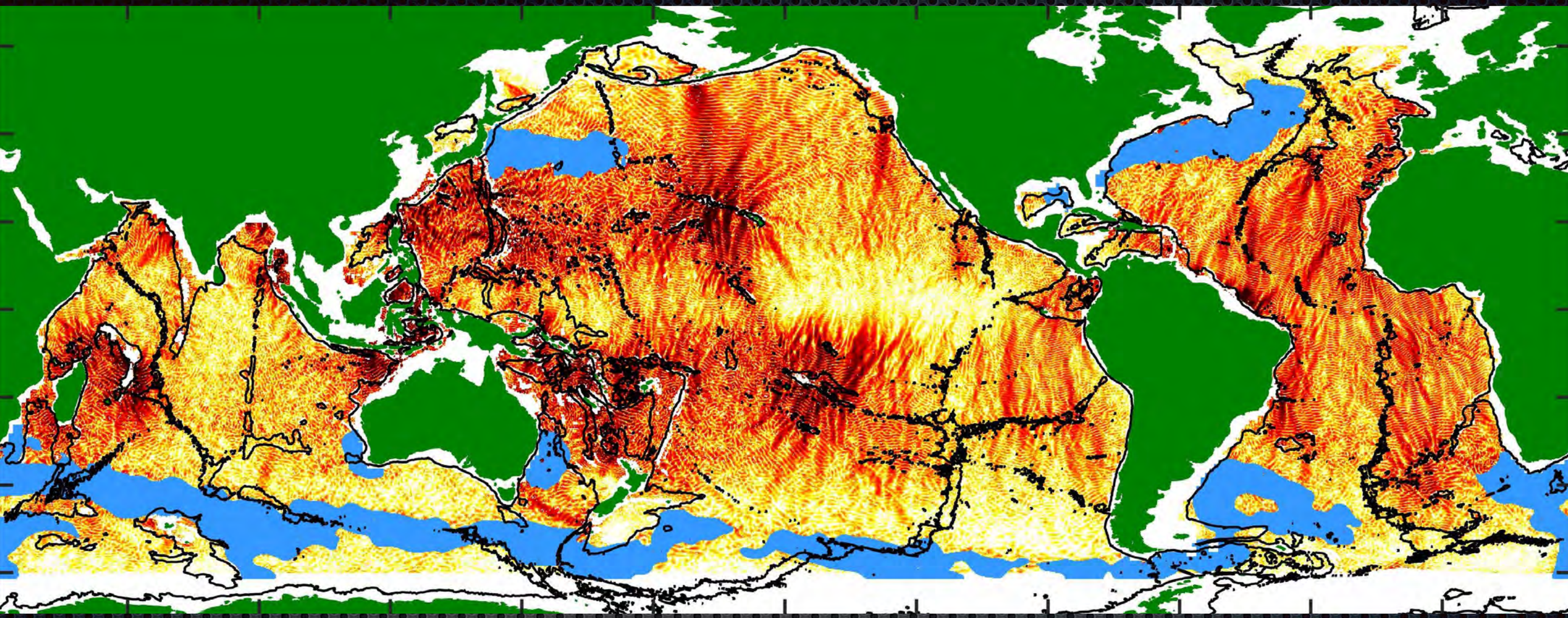
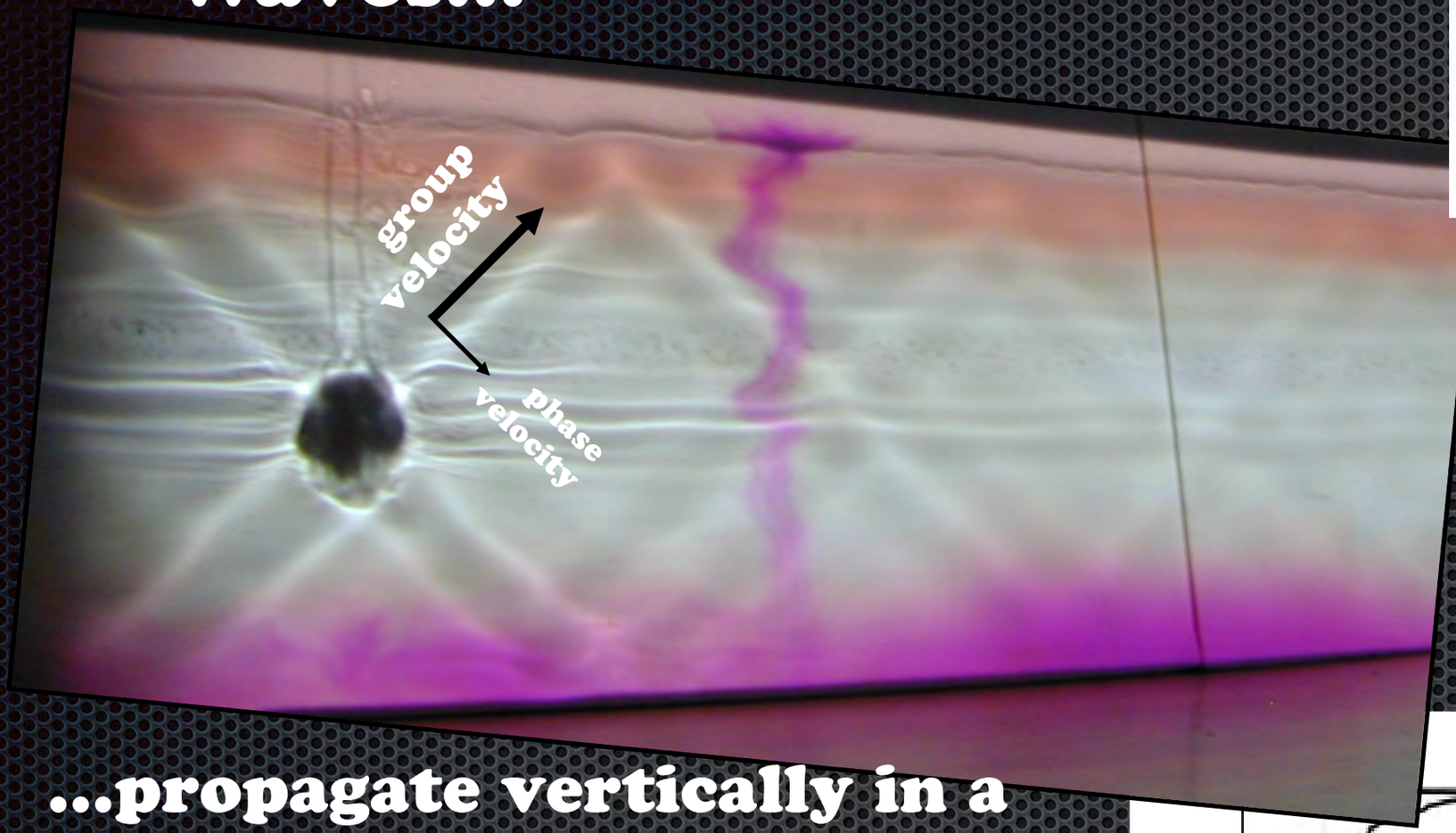


Toward Global Mixing Maps from Space

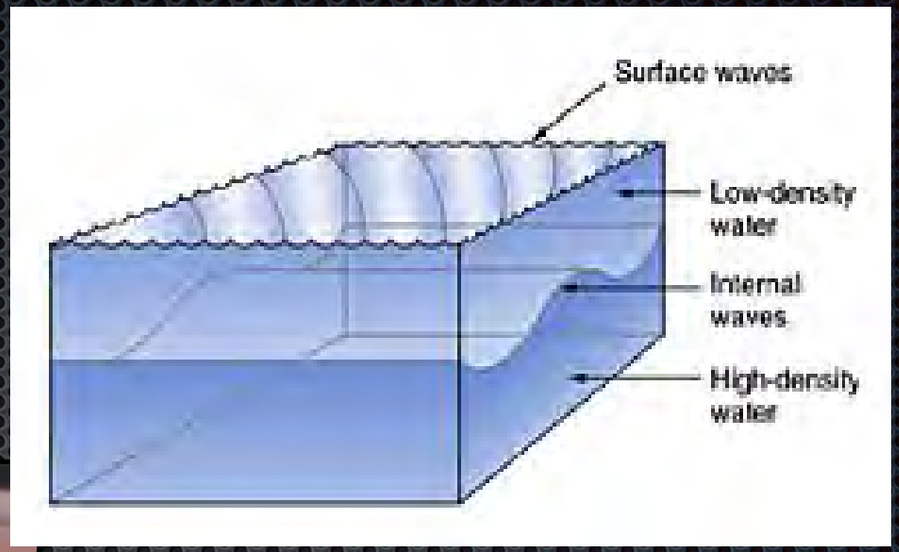
James B. Girton and Zhongxiang Zhao, Applied Physics Laboratory, University of Washington

Matthew H. Alford, Scripps Institution of Oceanography, UC San Diego

Internal Waves...

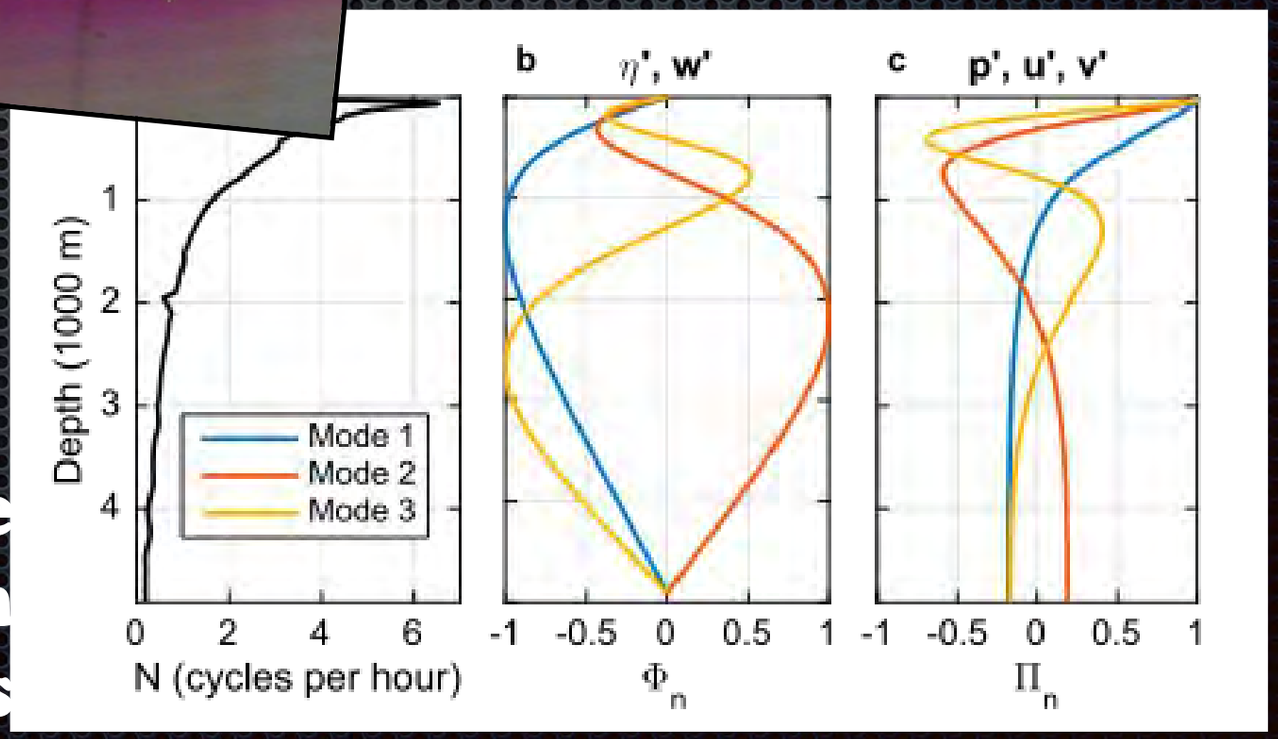


...propagate vertically in a continuously-stratified fluid

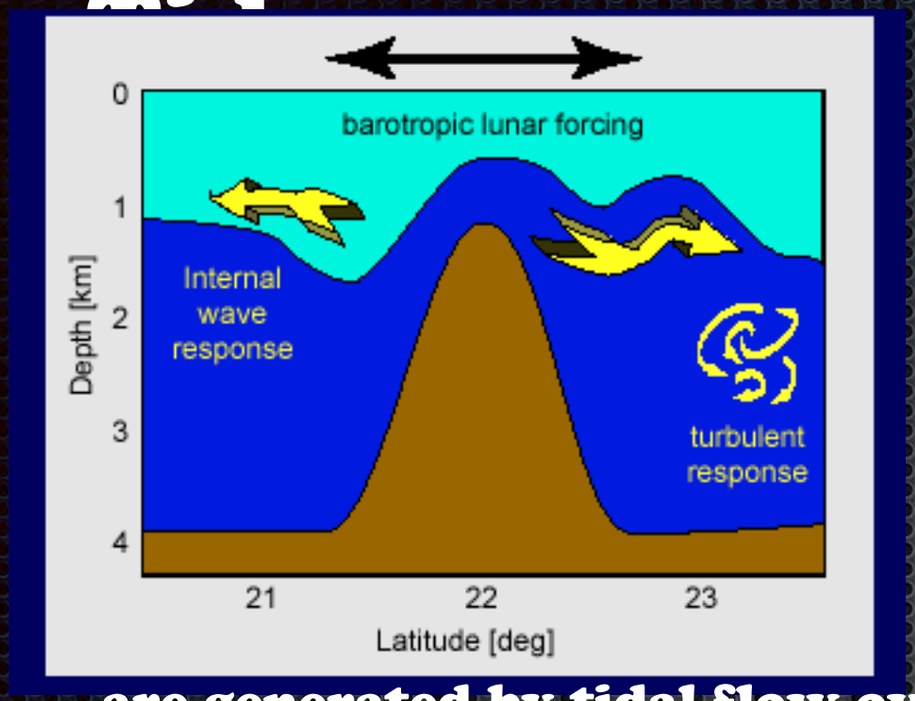


...form on the interface of a 2-layer fluid

...propagate horizontally in baroclinic modes



Internal



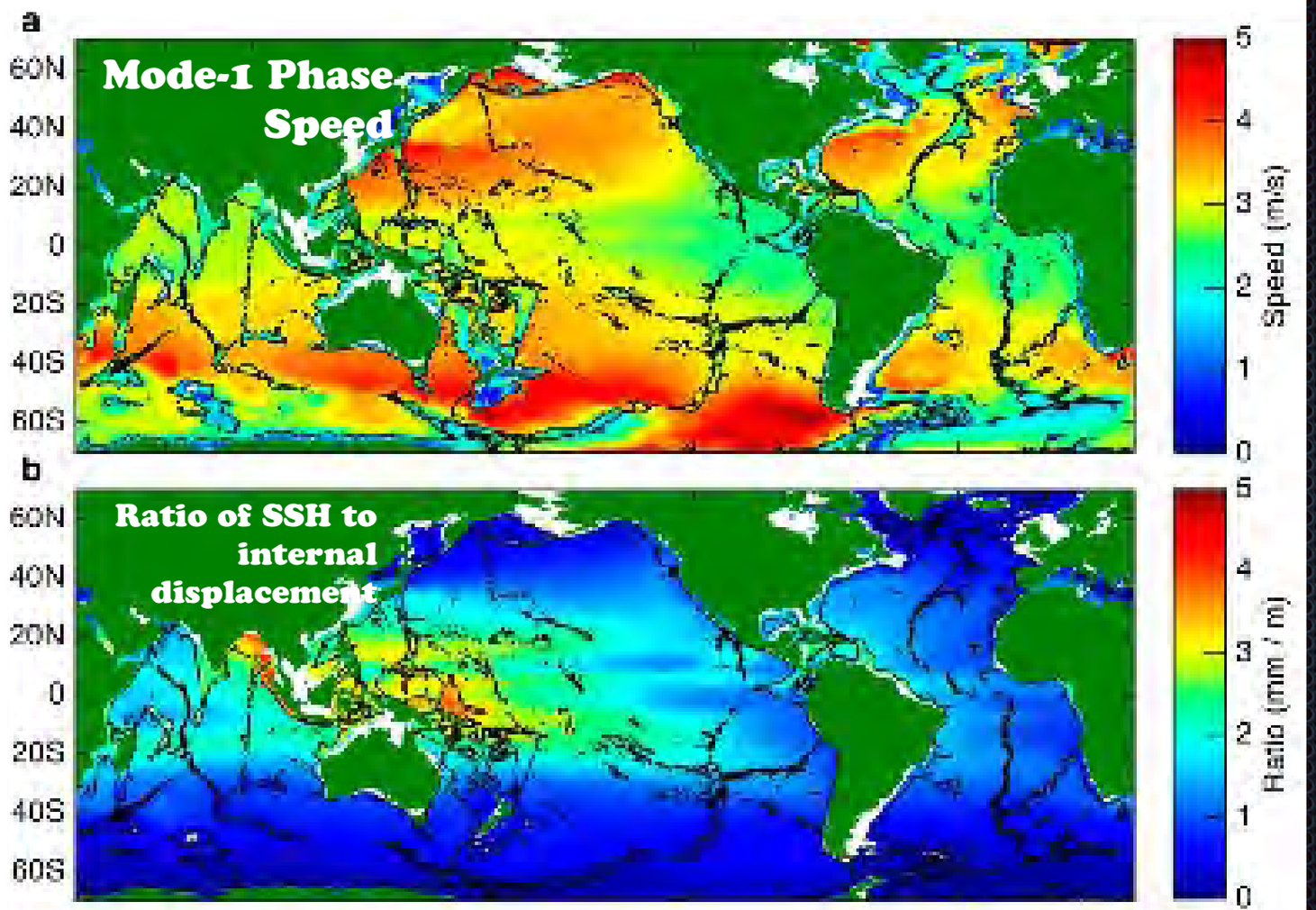
...are generated by tidal flow over rough bathymetry

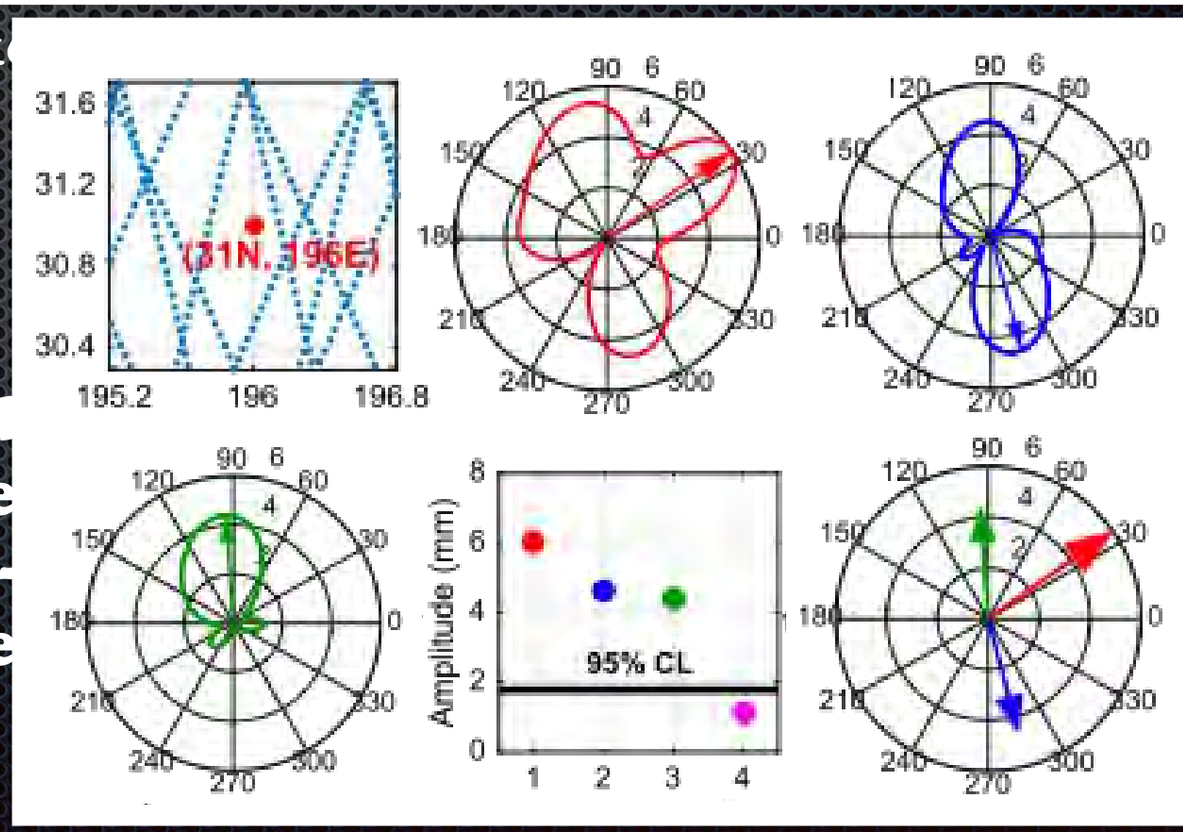
...are dominated by the lowest few baroclinic modes

...propagate at a speed set by the stratification, bathymetry, and mode #

...produce small sea-surface height perturbations (corresponding to the pressure perturbation at the

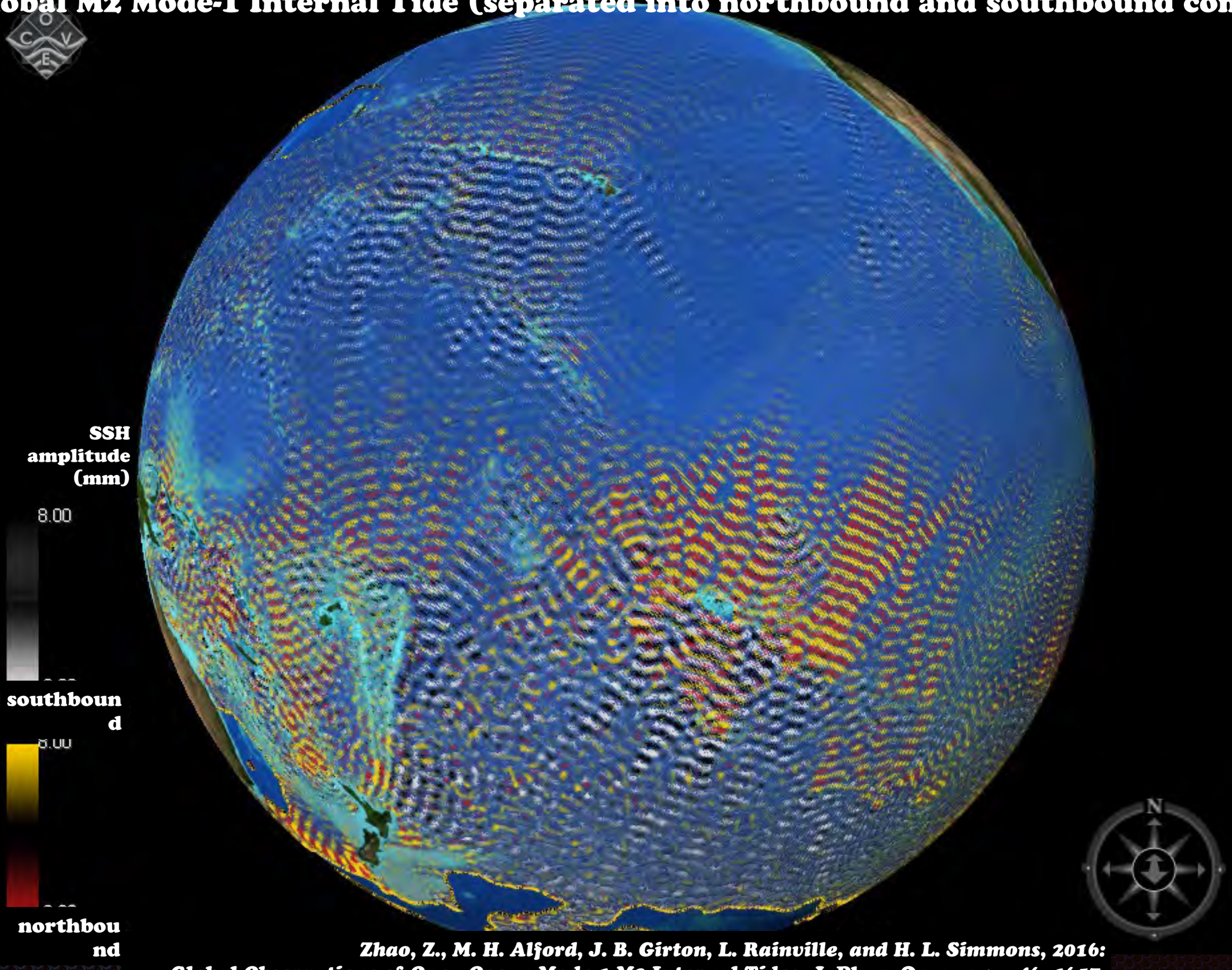
...can be extracted from satellite altimetry via a wave-fitting procedure





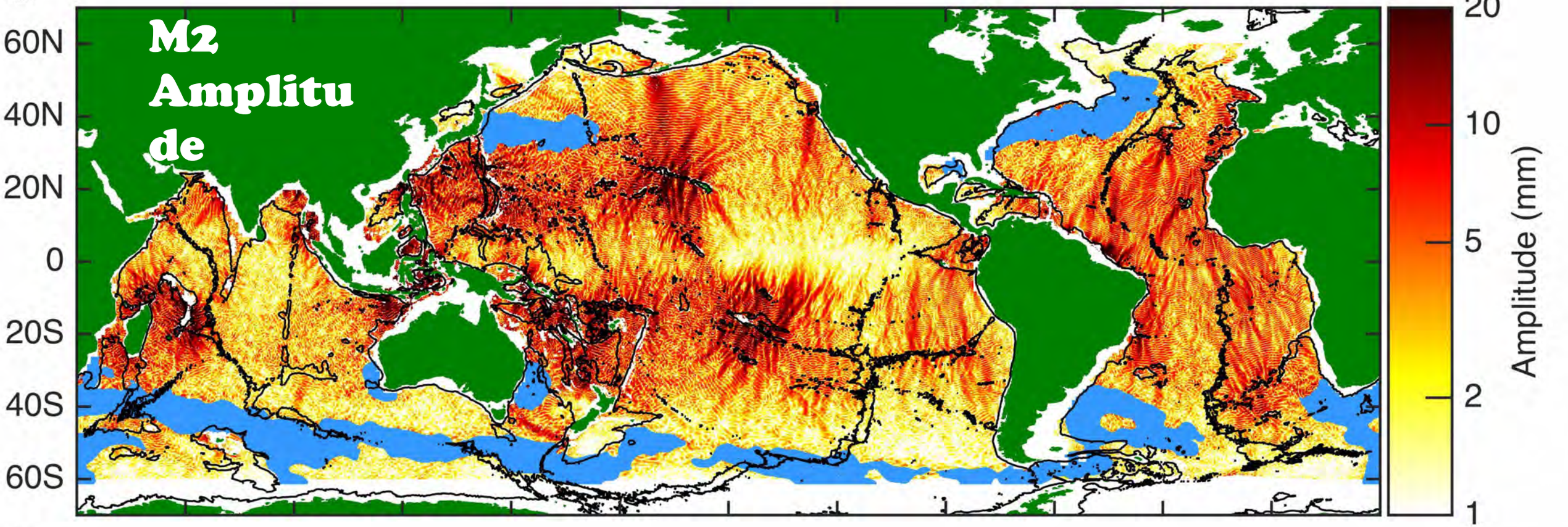
Zhao, Z., M. H. Alford, J. Girton, T. M. S. Johnston, and G. Carter (2011a), Internal tides around the Hawaiian Ridge estimated from multisatellite altimetry, *J. Geophys. Res.*, *116*, C12039, doi: 10.1029/2011JC007045

he Global M2 Mode-1 Internal Tide (separated into northbound and southbound compon

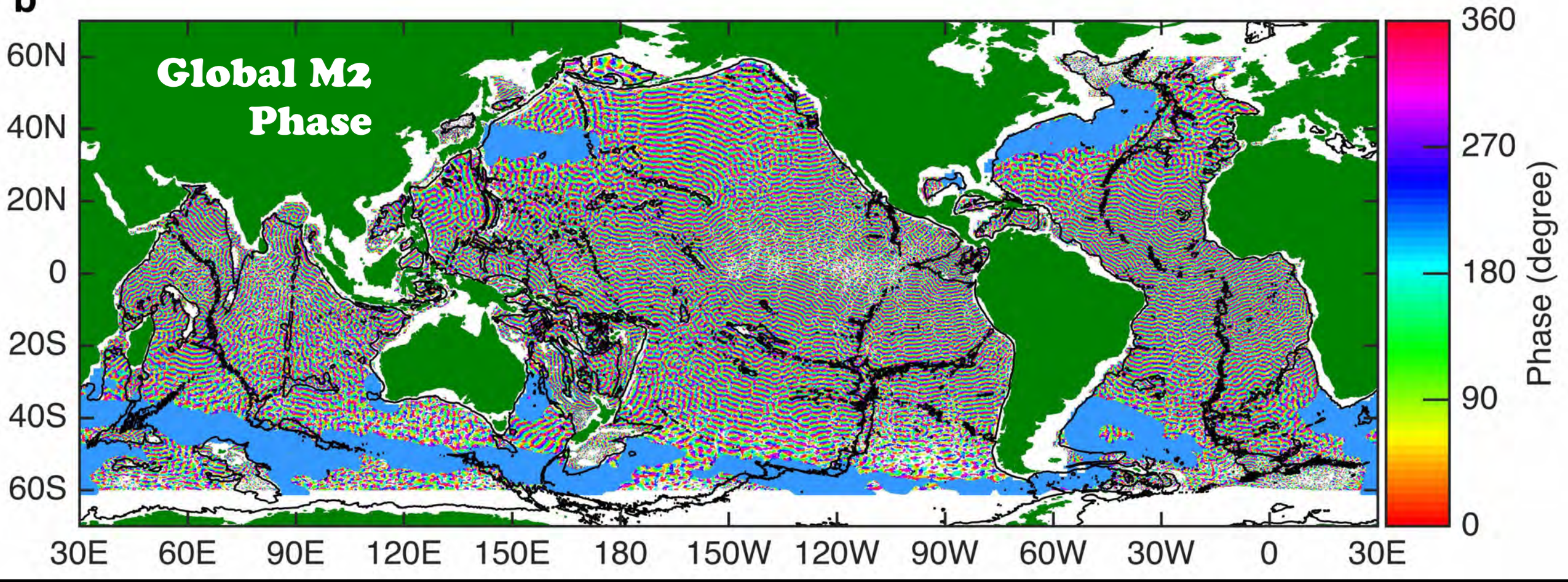


Zhao, Z., M. H. Alford, J. B. Girton, L. Rainville, and H. L. Simmons, 2016: Global Observations of Open-Ocean Mode-1 M2 Internal Tides, J. Phys. Oceanogr., 46, 1657-

a

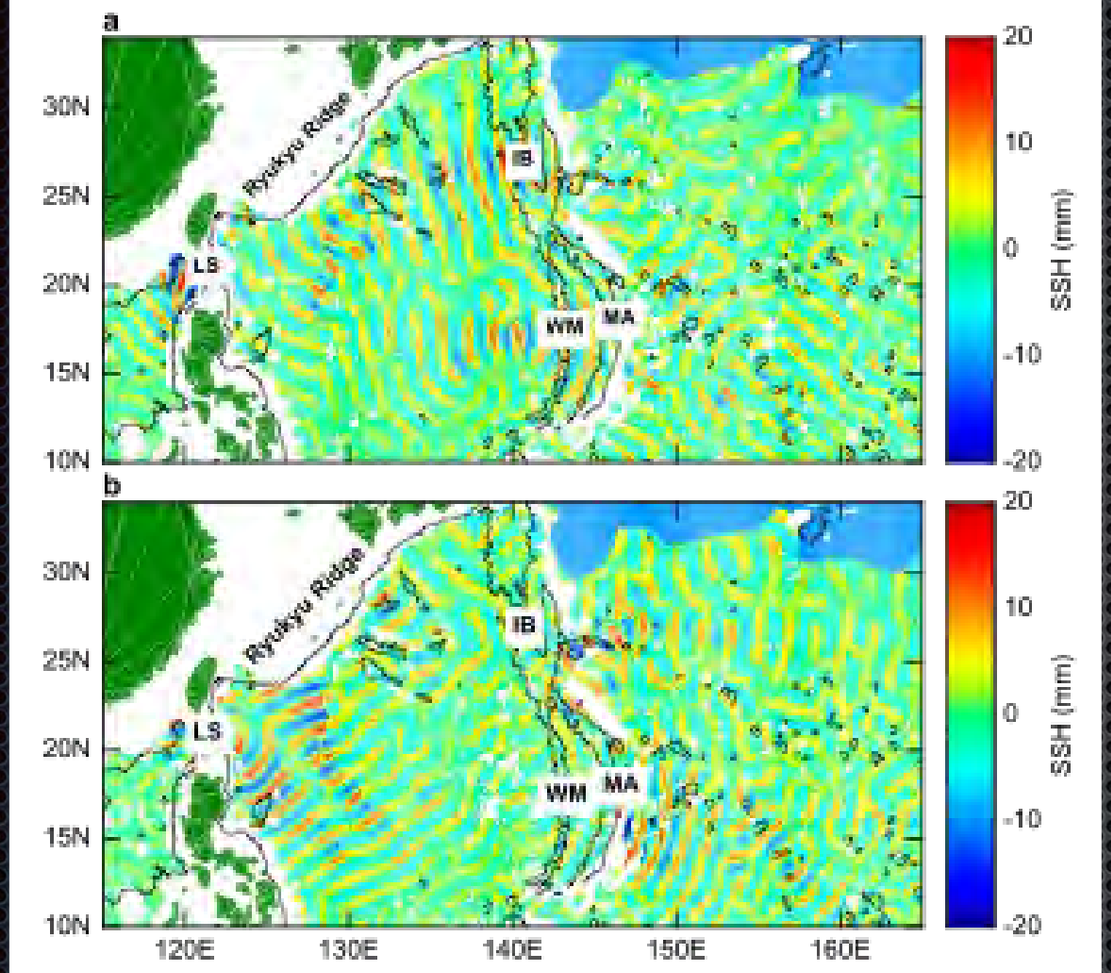


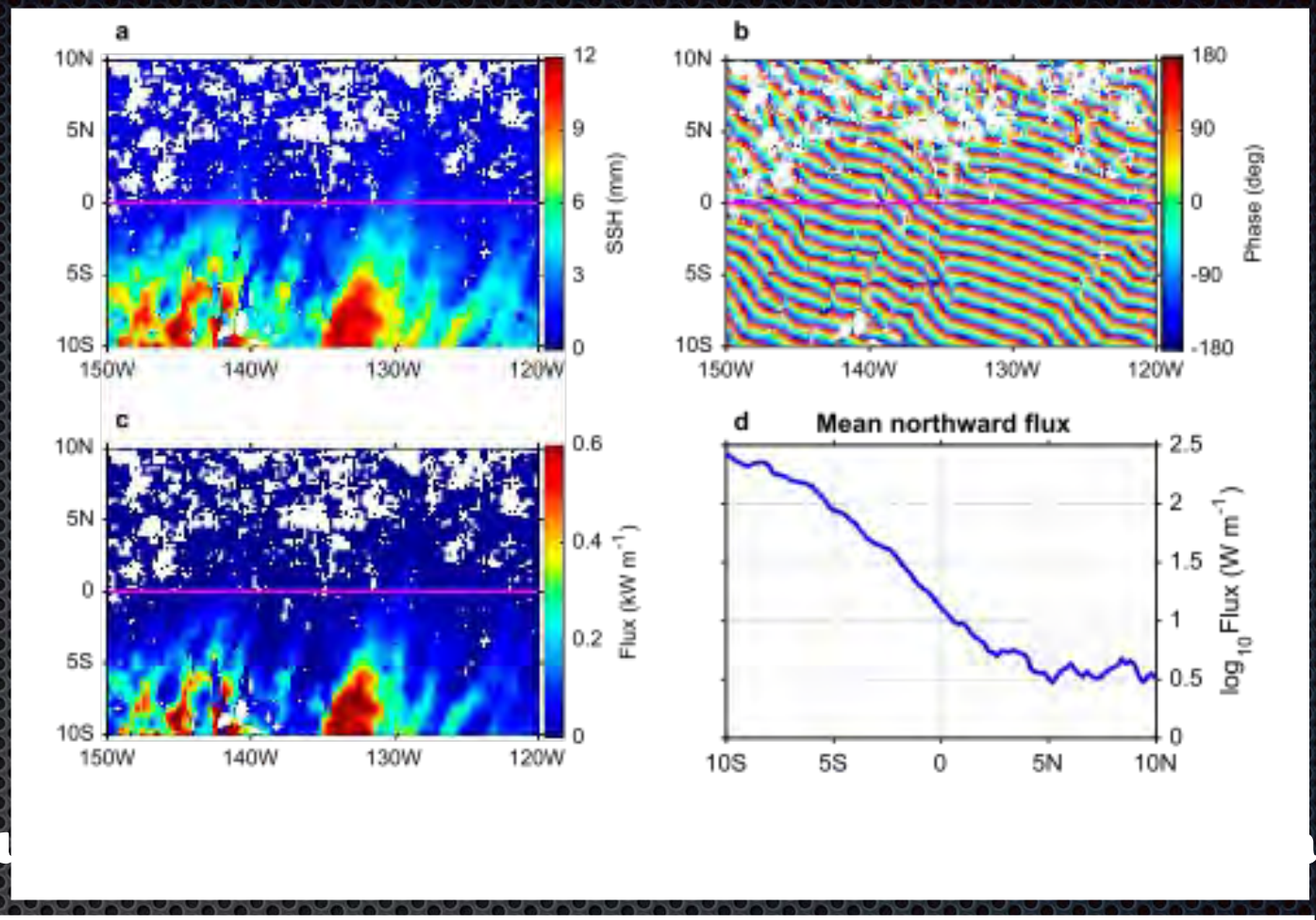
b



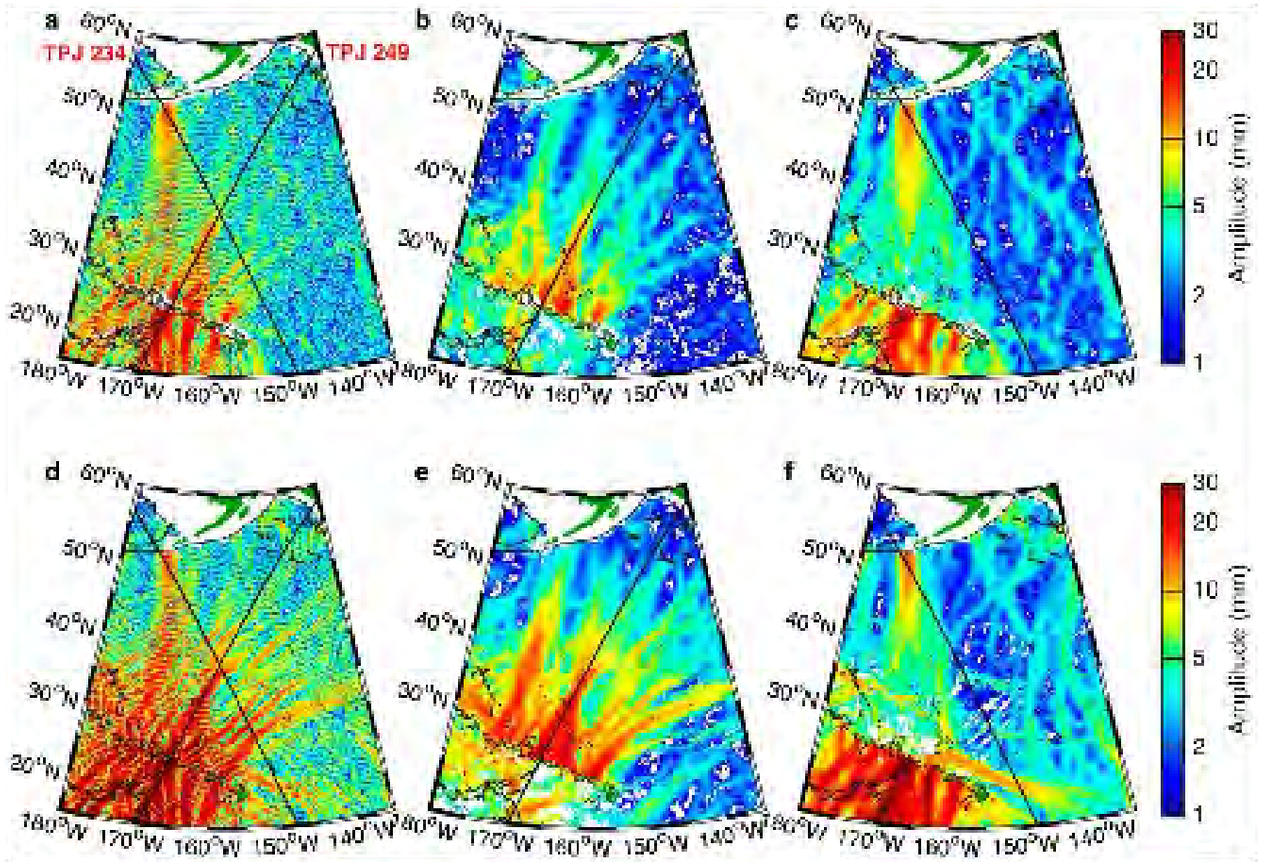
Zhao, Z., M. H. Alford, J. B. Girton, L. Rainville, and H. L. Simmons, 2016: Global Observations of Open-Ocean Mode-1 M2 Internal Tides, J. Phys. Oceanogr., 46, 1657

Regional M2 Examples





Sou



Com

Zhao, Z., M. H. Alford, J. B. Girton, L. Rainville, and H. L. Simmons, 2016: Global Observations of Open-Ocean Mode-1 M2 Internal Tides,

Diurnal Internal Tides

Wave-fitting technique is applicable to other frequencies and baroclinic modes, including solar components (by omitting sun-synchronous altimeters).

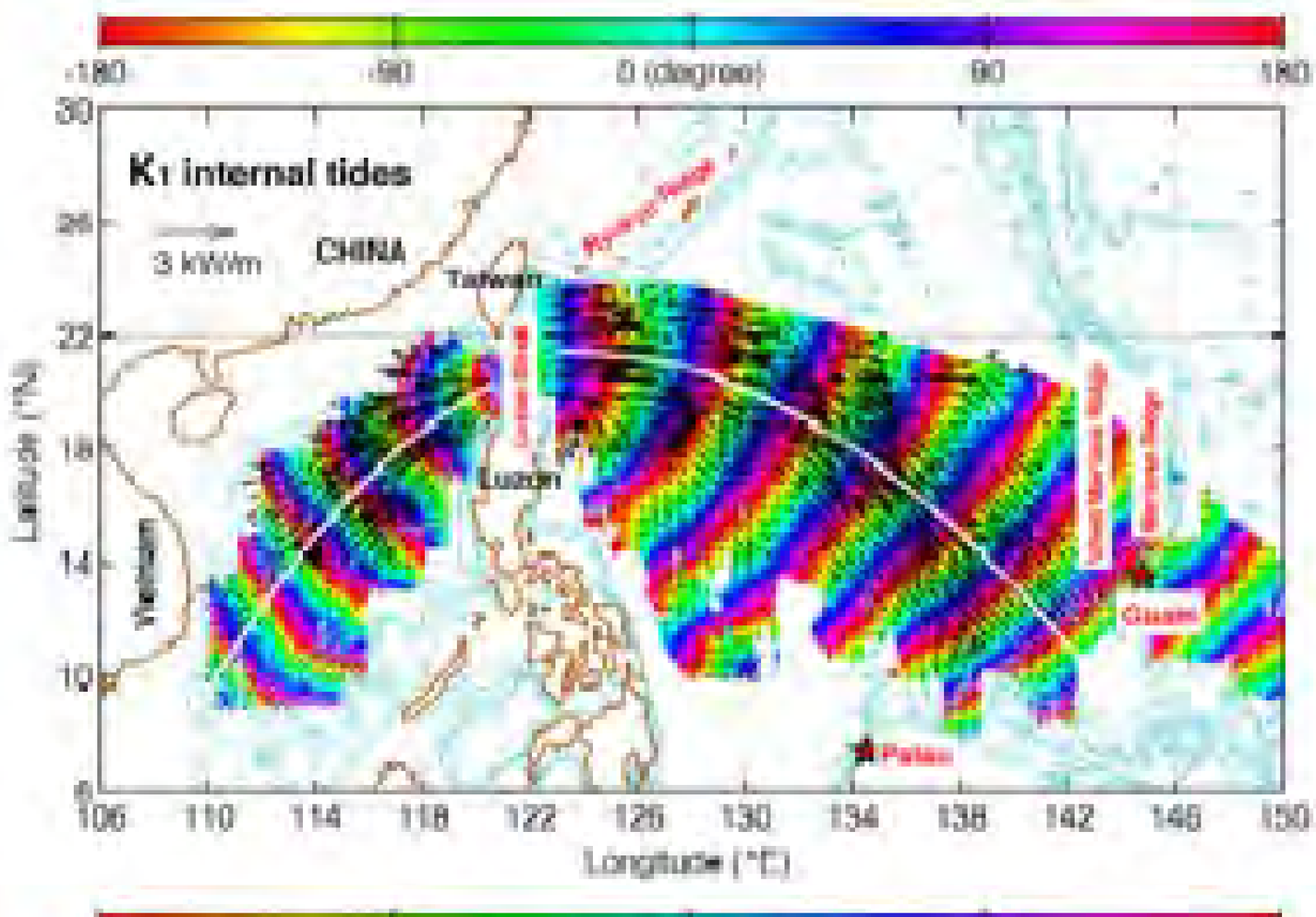
But free wave speed becomes infinite where tidal frequency equals inertial, so topographically trapped sub-inertial waves are not found.

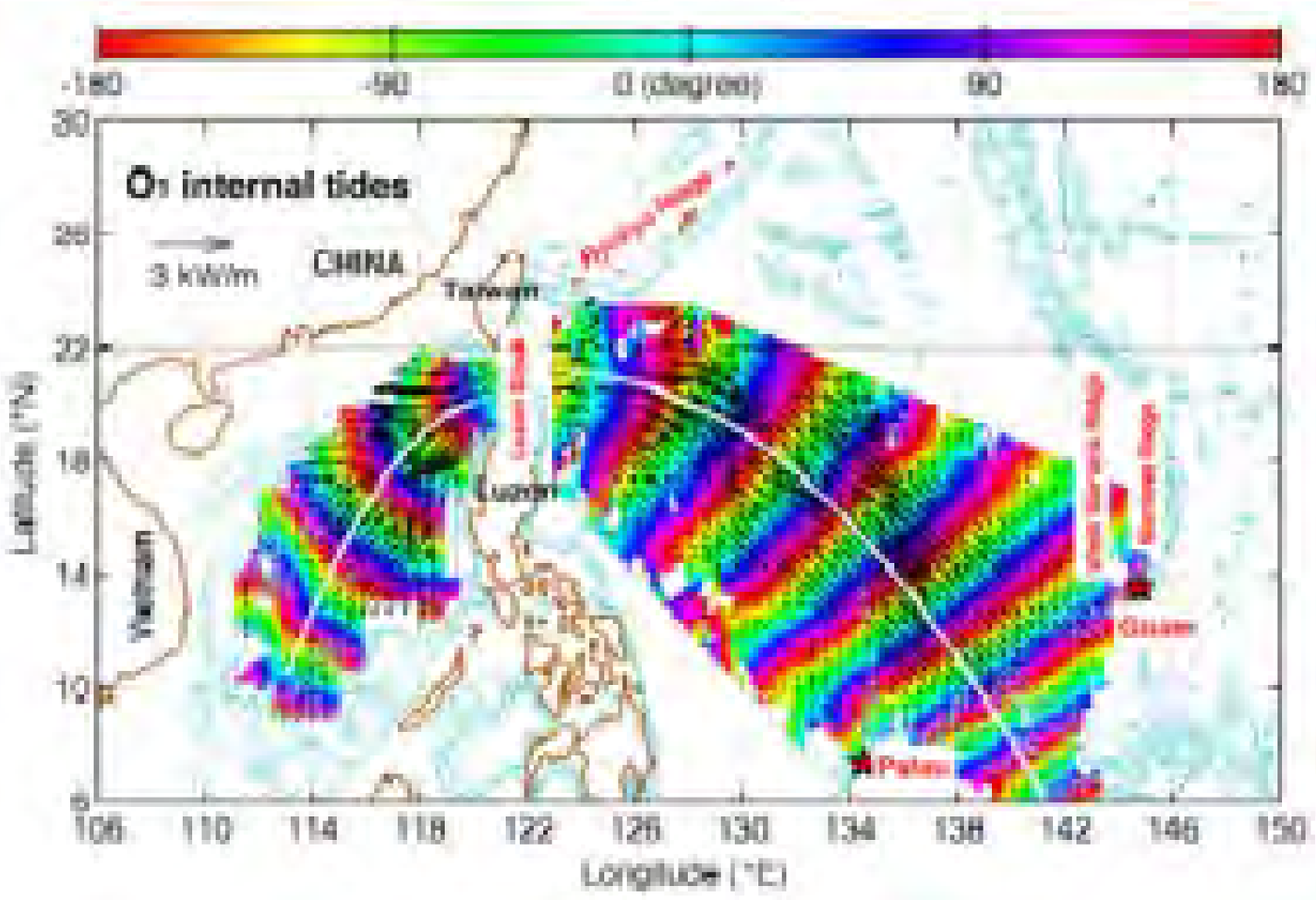
Regional Diurnal Example: Luzon Strait

- East and west-bound waves follow curved theoretical mode paths

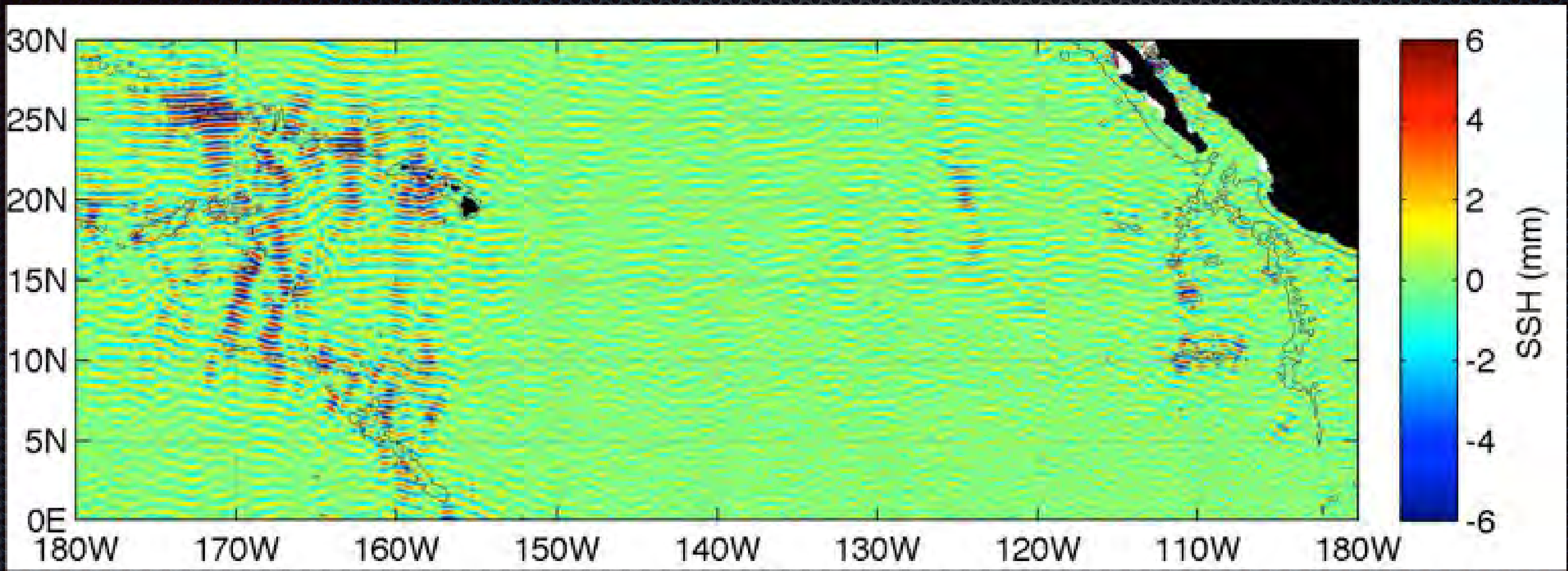
- O_1 waves are weaker and curve more rapidly due to lower frequency

Zhao, Z., 2014: Internal tide radiation from the Luzon Strait. J. Geophys. Res. Oceans, 119, 5434–5448, doi:10.1002/ 2014JC010014.





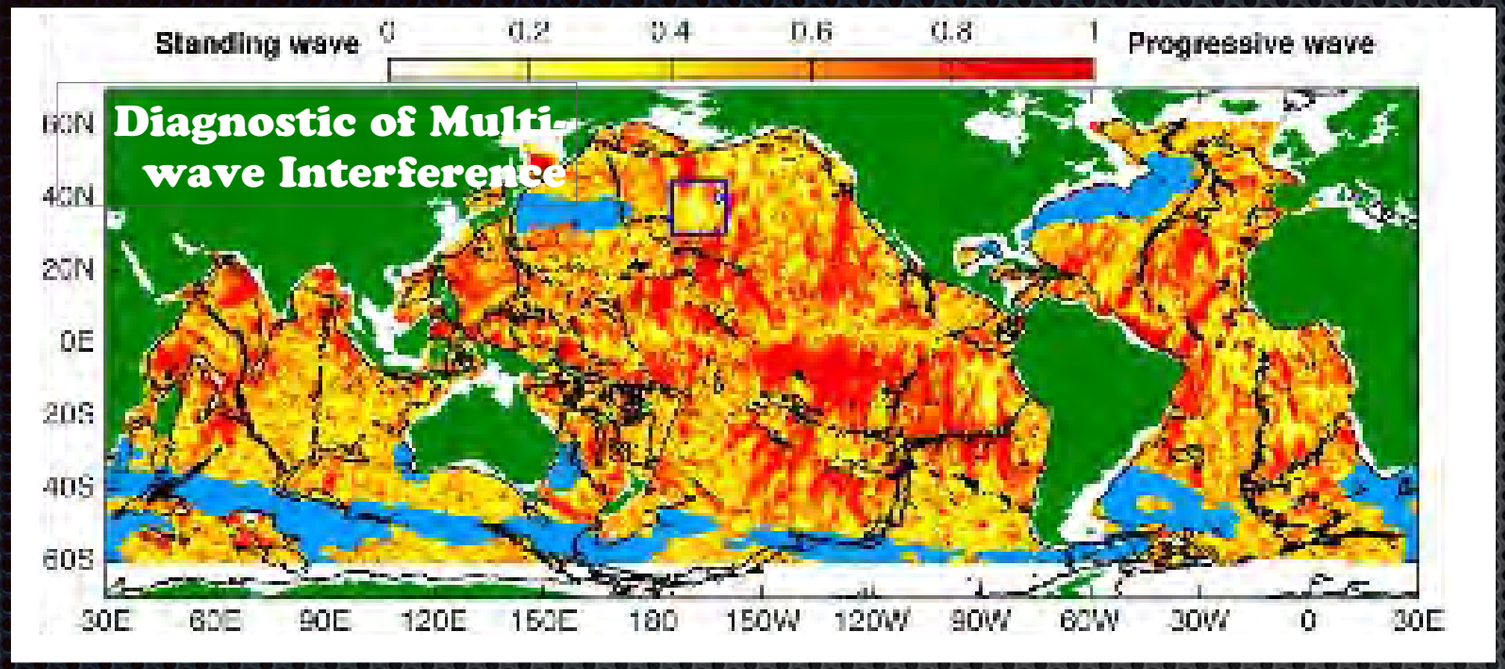
Mode-2 (M2) is also visible from space

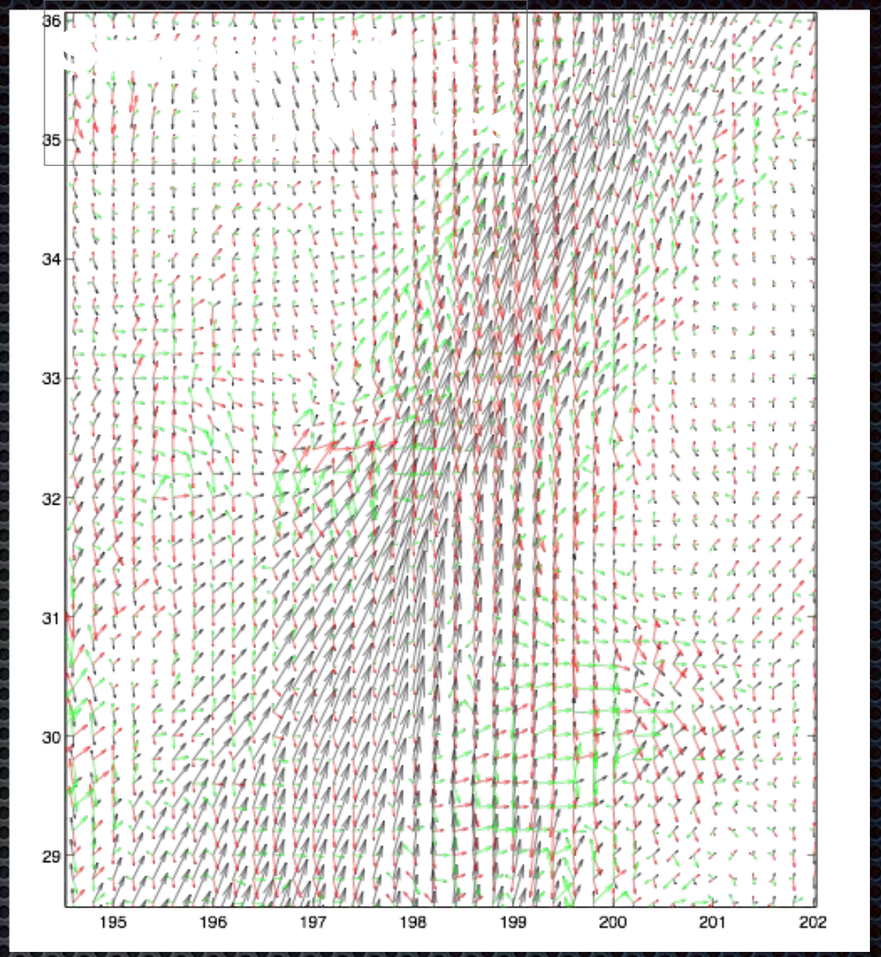


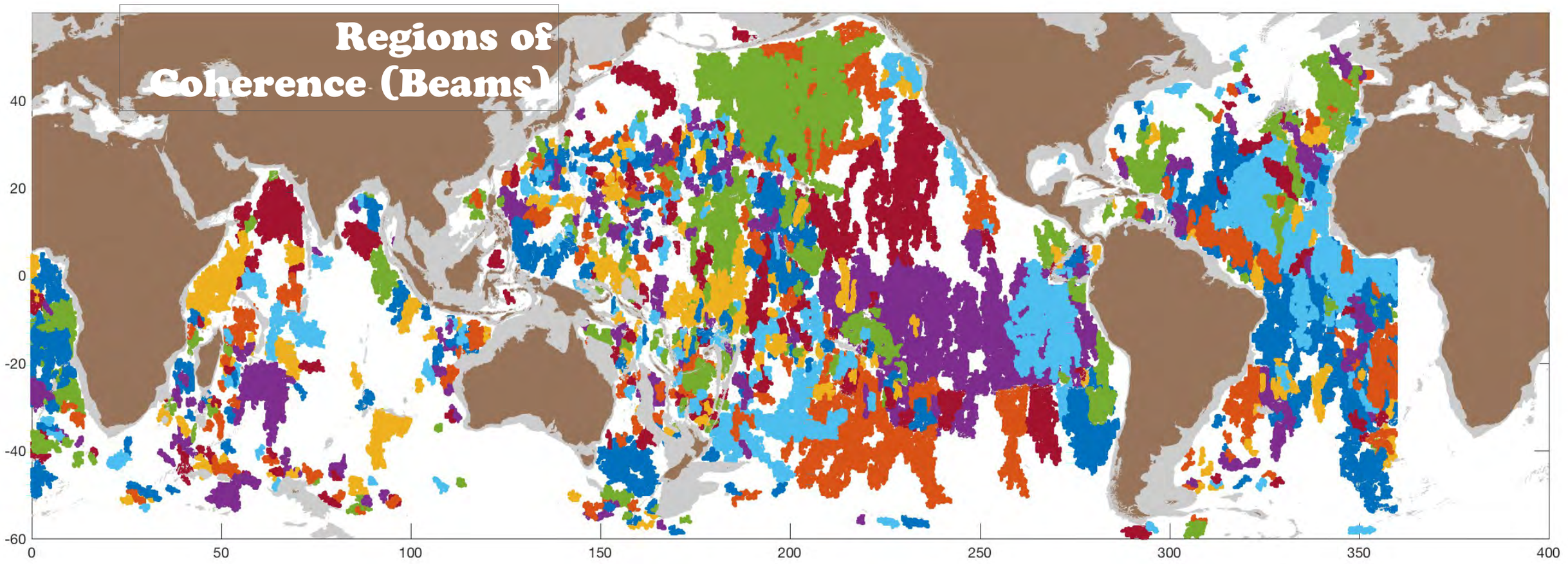
- Extracted using a 60-120 km pre-filter before fitting to the mode-2 wavelength
- Narrower beams and less propagation distance
- Multiple generation sites south of Hawaii

Zhao, Z., M. H. Alford, and J. B. Girton (2012a), Mapping low-mode internal tides from multisatellite altimetry, Oceanography, *25 (2), 42–51*.

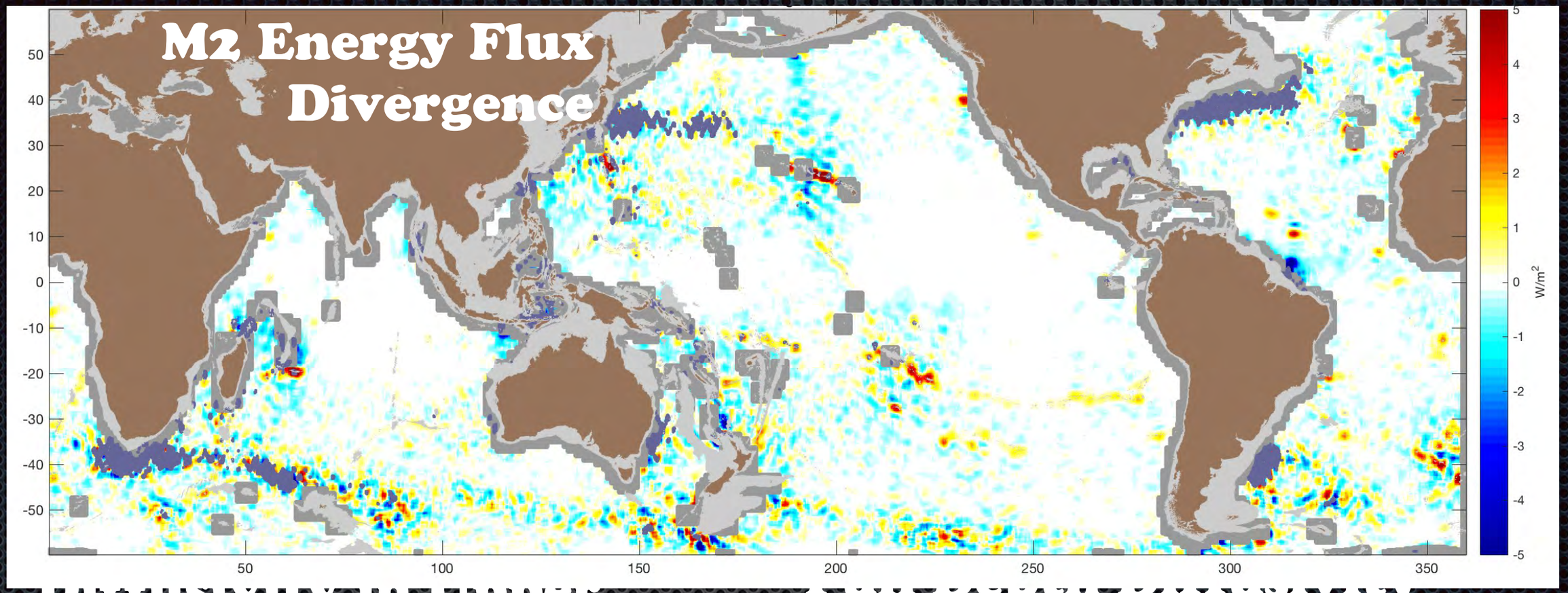
Identifying distinct beams in the multi-wave product

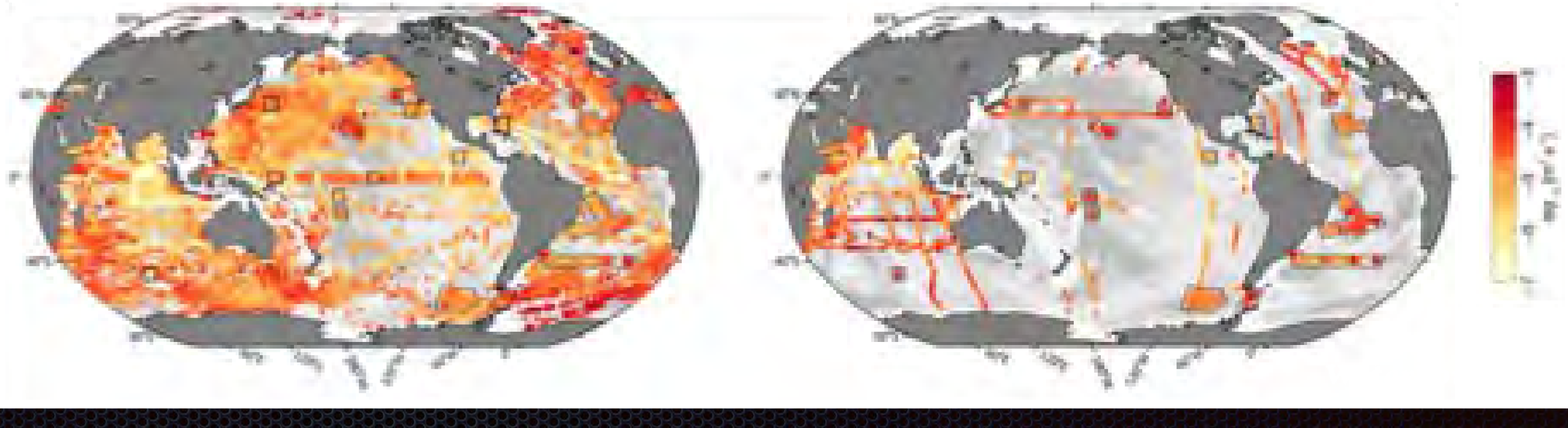




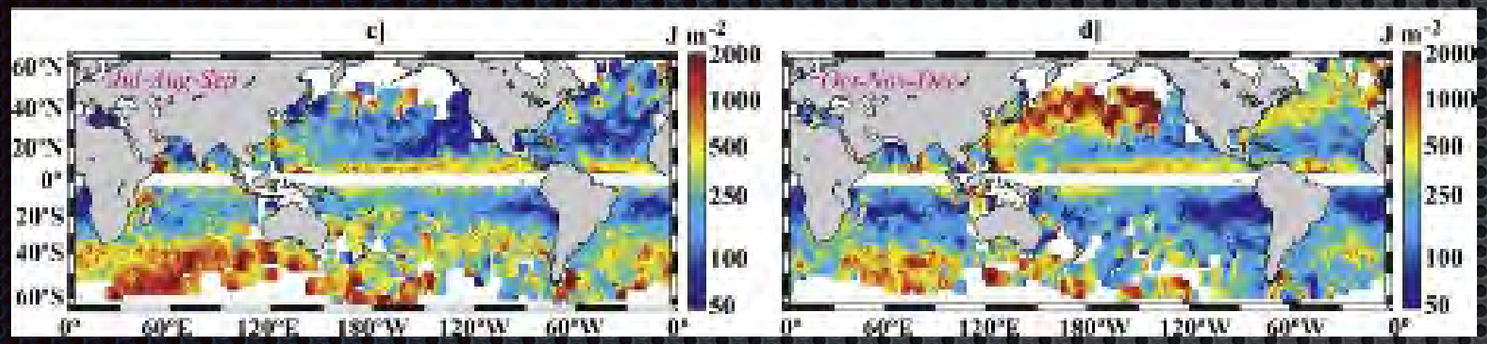


Toward Global Mixing Maps

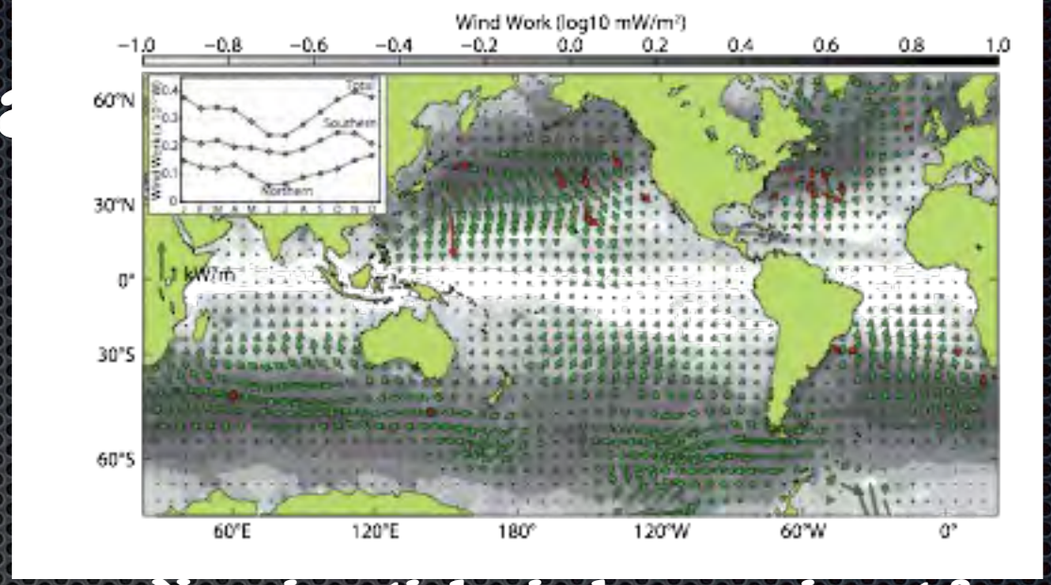




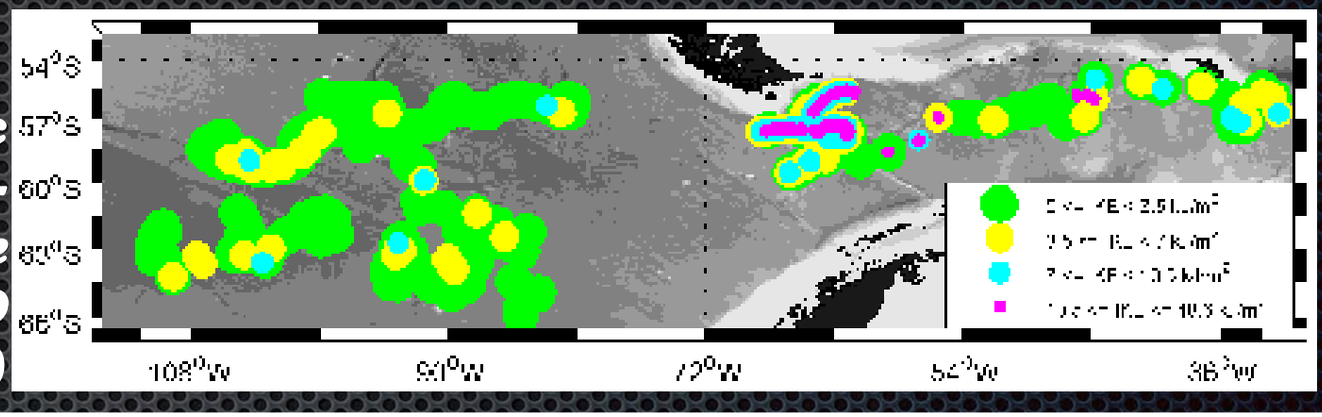
Toward global near-inertia internal wave properties



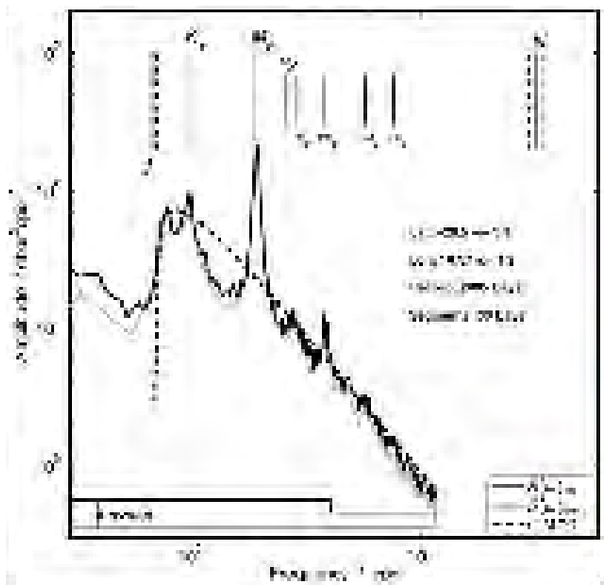
Surface near-inertial kinetic energy from drifters (*Chaigneau et al, GRL 2008*)

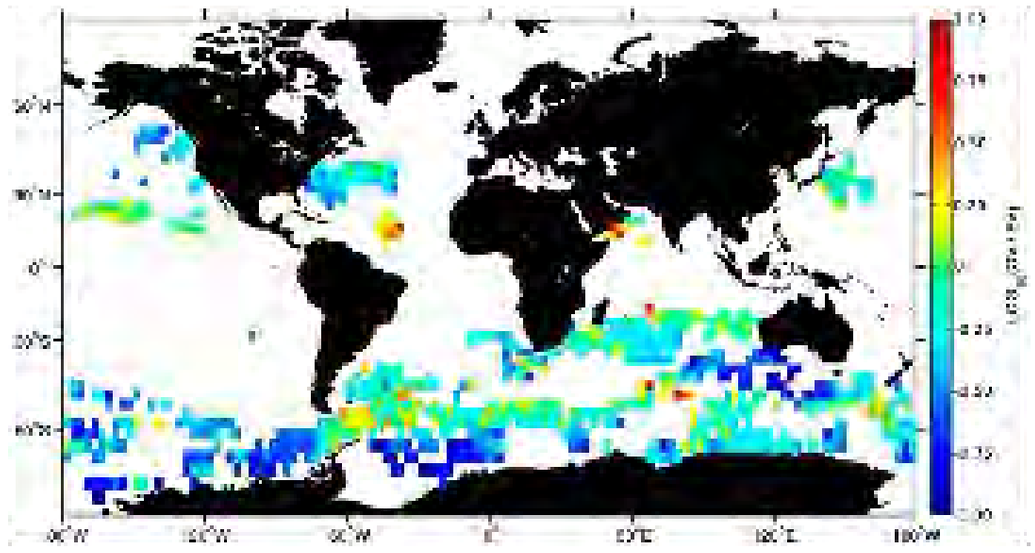


Near-inertial wind-energy input from reanalyses and horizontal flux from models and moorings (*Simmons and Alford, Oceanography 2012*)



Subsurface near-inertial kinetic energy from profiling float half-inertial velocity sampling (*Kilbourne and Girton, JPO 2015; Meyer et al, JPO 2015*)

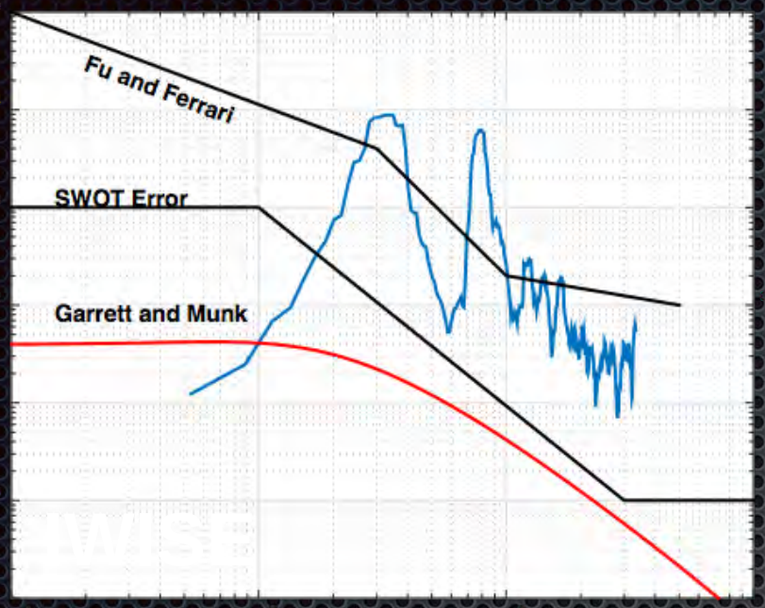


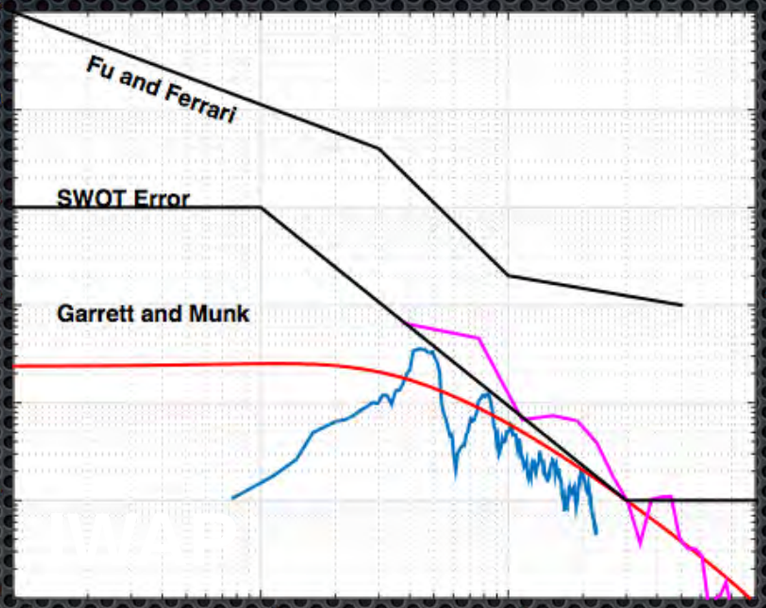


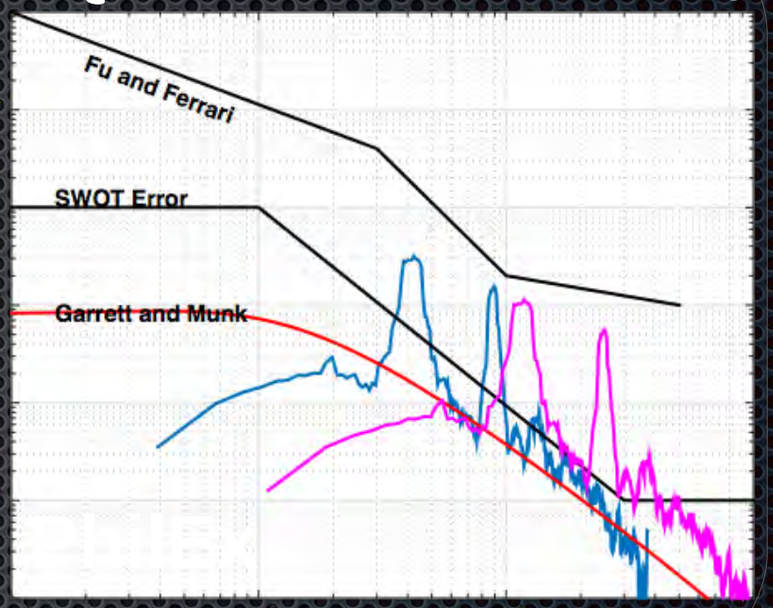
Subsurface near-inertial kinetic energy from Argo vertical displacements during park phase (*Hennon et al, JPO 2014*)

SSH from Non-tidal IWs (inferred from observations)

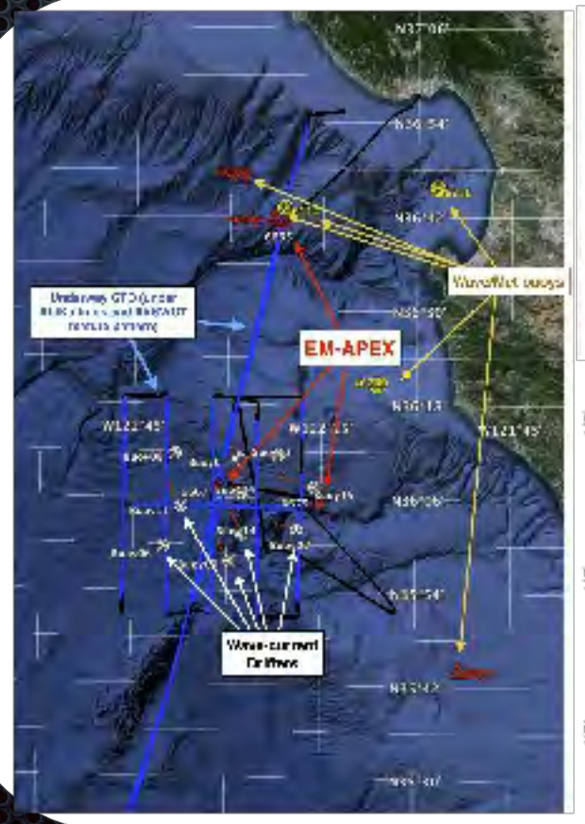
Moored dynamic height frequency spectra converted to wavenumber (though with incomplete mode information)

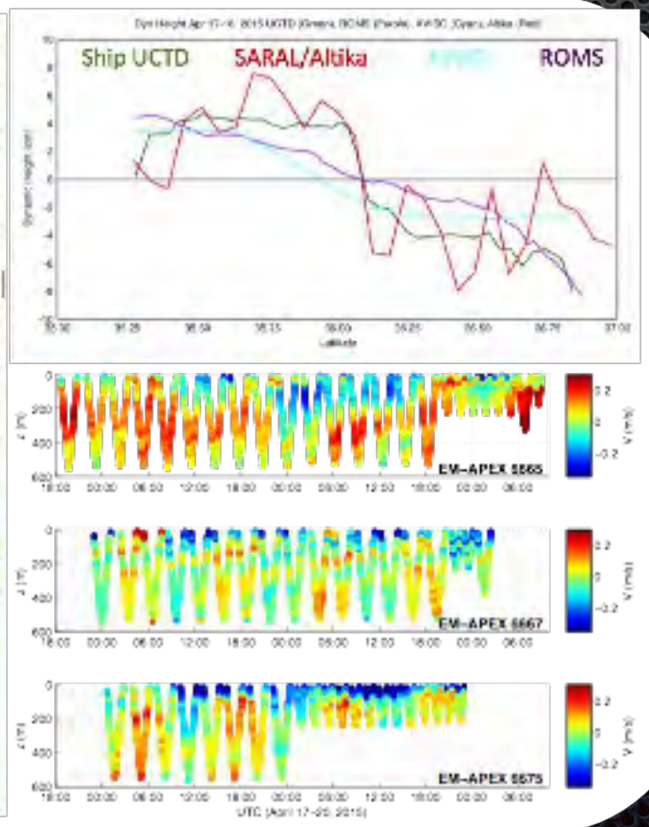


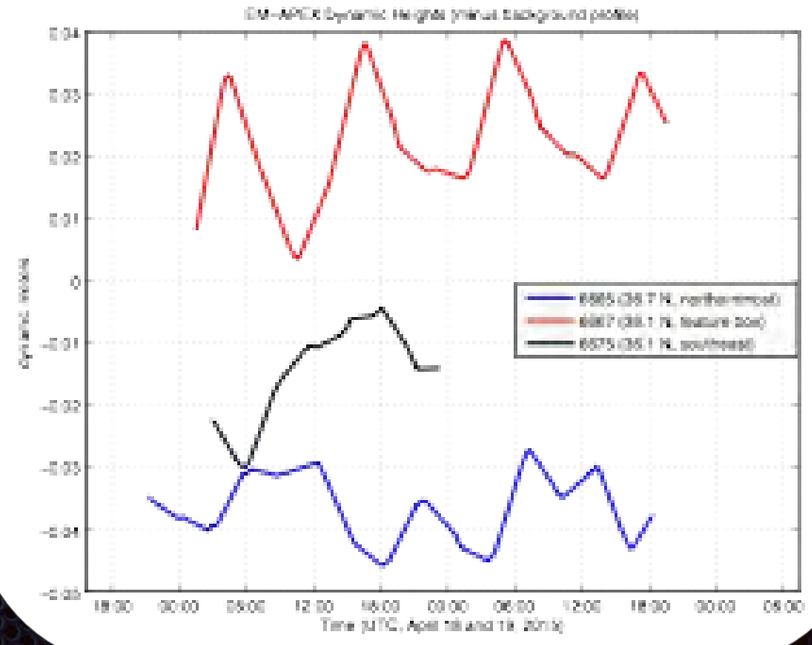


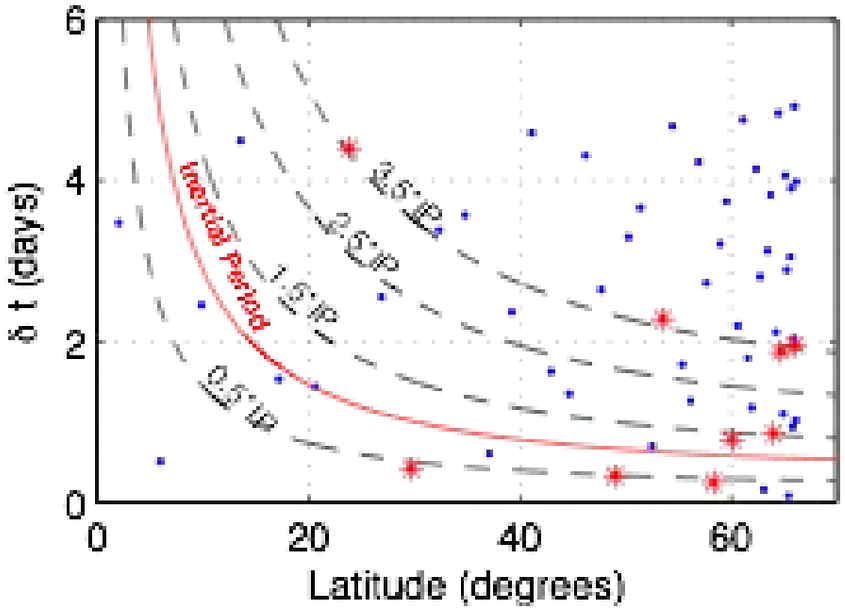


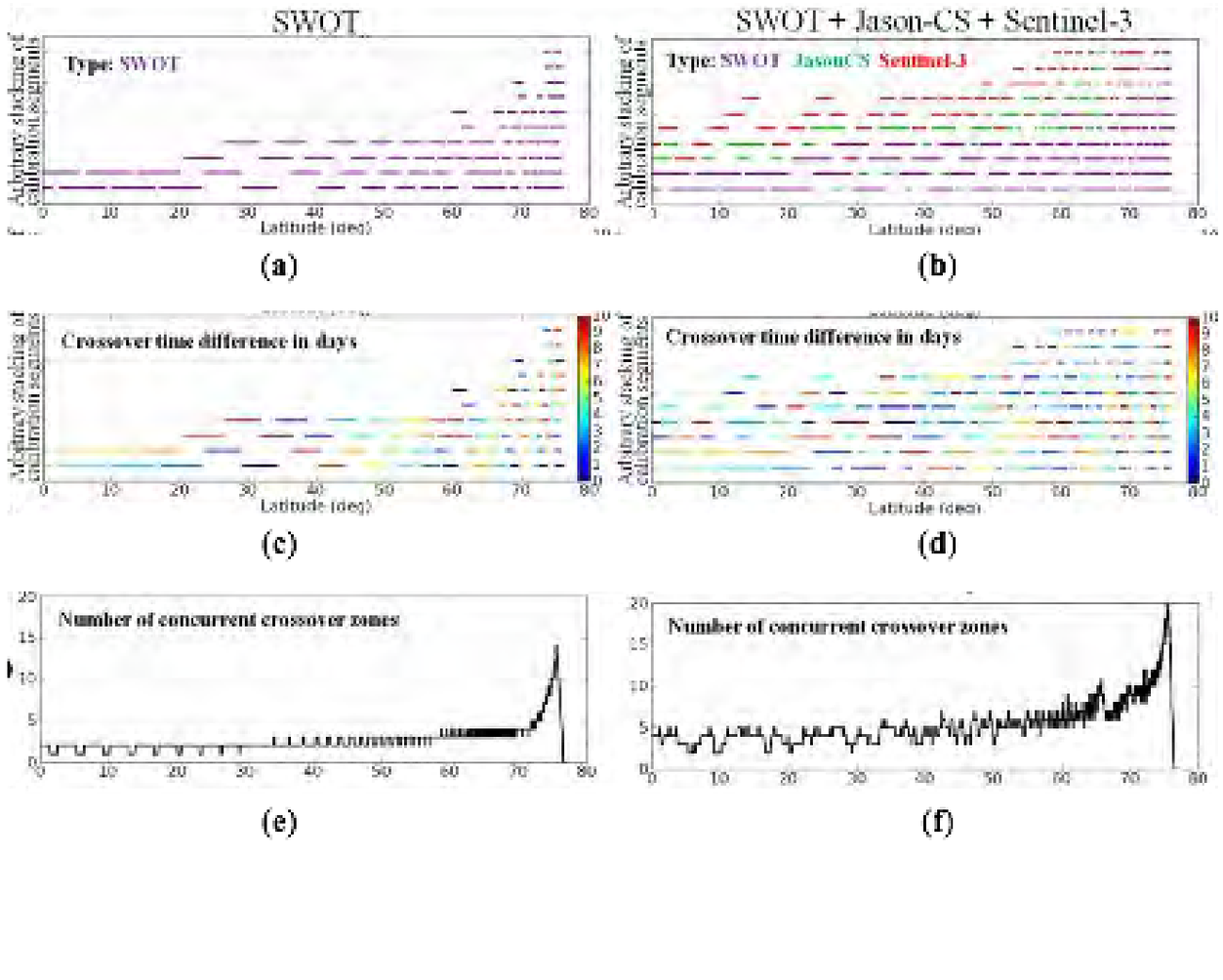
Internal Tide SSH








6
4
2
0
δ t (days)
0
20
40
60
Latitude (degrees)
Inertial Period
0.5 IP
1.5 IP
2.5 IP
3.5 IP


SWOT
SWOT + Jason-CS + Sentinel-3
Type: SWOT
Type: SWOT Jason-CS Sentinel-3
Crossover time difference in days
Number of concurrent crossover zones
Latitude (deg)
(a)
(b)
(c)
(d)
(e)
(f)

Conclusions

- The global mode-1 M2, S2, K1 and O1 altimetric internal tide results are available. Contact us (e-mails below), or see Outreach presentation file for link to M2 movies.
- Dynamics and wave separation techniques are a promising way to enhance interpretation (dissipation, generation, beams, etc.)
- The SSH contribution from internal waves (and observability from satellites) is dominated by internal tides, but the background (Garrett-Munk) continuum may be visible where other contributions are small.
- Observational validation for continuum internal wave SSH requires coverage of lowest modes.

Next Steps

ear-inertial energy from crossovers.

ngerprints of internal wave wavenumber spectra in altimetry.

future altimeter trailing phase optimized for internal wave sampling?

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