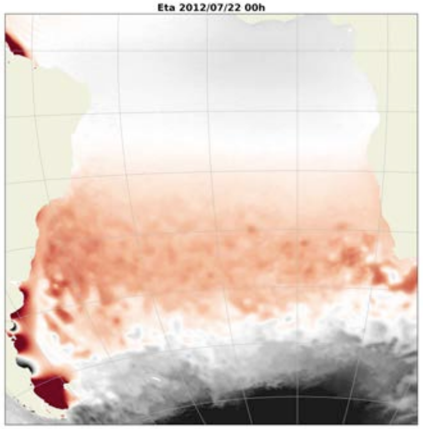
distinguishing internal waves and balanced motions in SWOT data: a (non-exhaustive) review

Aurélien Ponte LOPS/Ifremer

motivations:

- SWOT = exceptional opportunity to improve our understanding of internal wave life cycles in the ocean and its impact on the longer term circulation
- operational: estimate ocean state circulation

SSH



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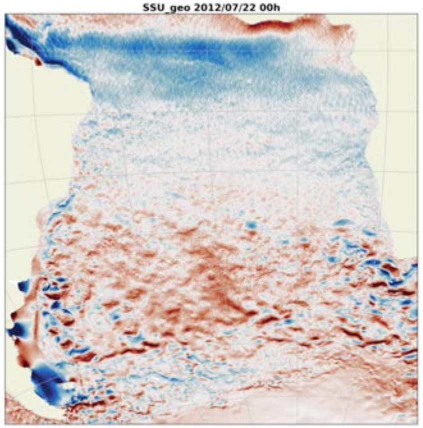
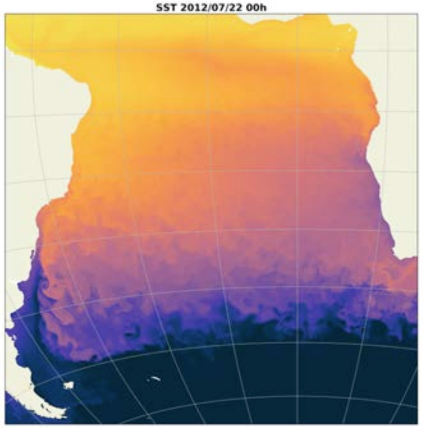


SST



what theory tells us

primitive equations

"weak flow" assumption
linearization around rest
small Rossby number

defining properties

balanced flow / slow mode
geostrophic / non-divergent
steady
potential vorticity

inertia-gravity waves / fast modes
lower/upper frequency bounds
propagating feature
dispersion relationship omega(k)
polarization relations
no (QG) potential vorticity

approx. reliability

dynamical models

balanced models:
quasi-geostrophy&co.

linearized (Kelly, Dunphy)
temporal filtered (Wagner et al. 2017,
more exotic)

canonical spectral distributions

QG turbulence theory:
k^{-3} kinetic energy
k^{-5} SSH

internal waves continuum
GM spectrum
k^{-2} kinetic and SSH (small scales)

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defining properties

Balanced flow / slow mode
geostrophic / non-divergent
steady
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inertia-gravity waves / fast modes
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propagating feature

building blocks to distinguish both types of motions

dynamical models

approx. reliability

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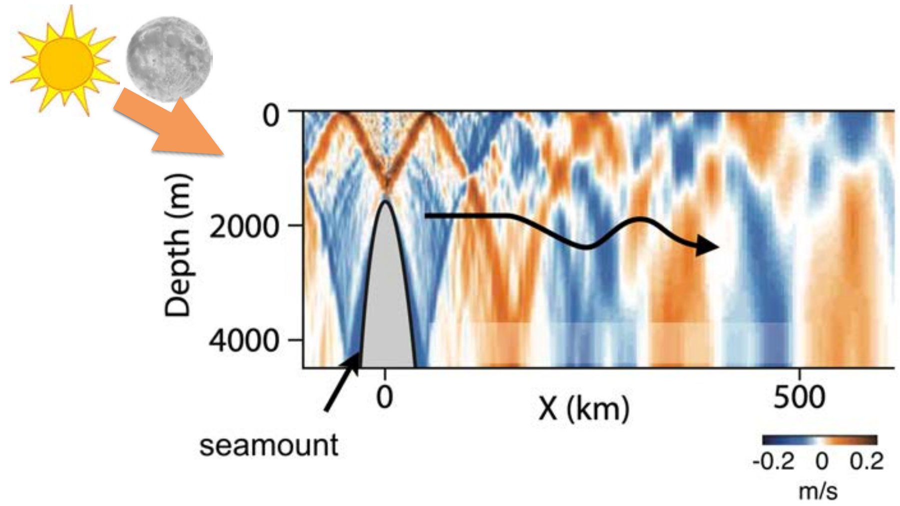
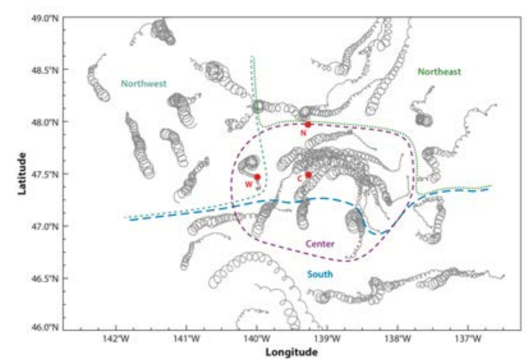
focus on internal gravity waves: forcings

Tides



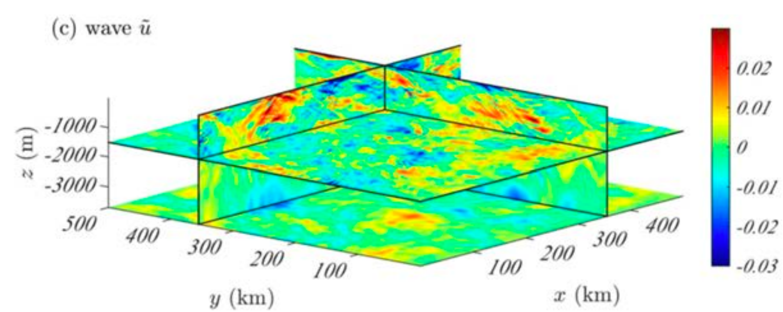
Klymak et al. 2012

Winds



Alford et al. 2016

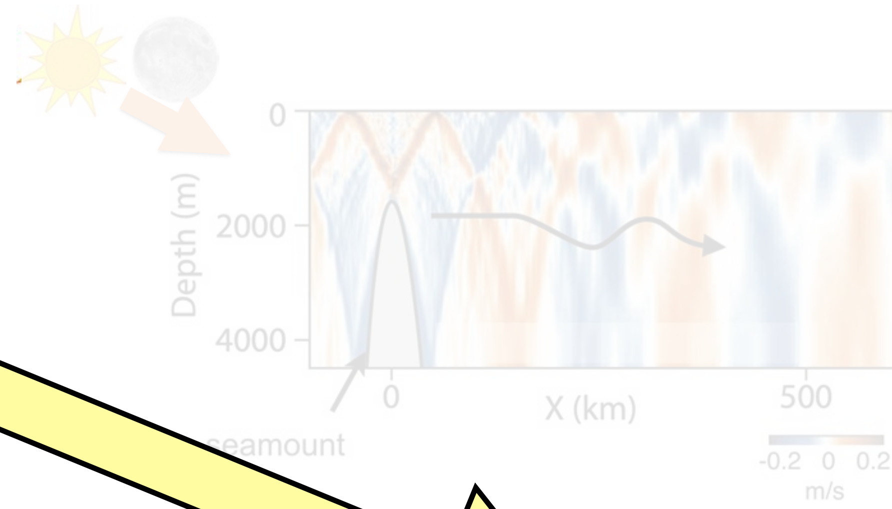
Balanced flow



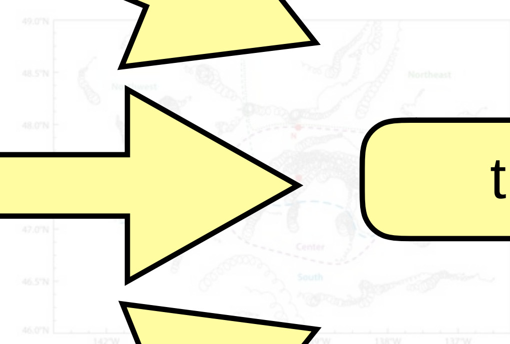
Shakespear and Hogg 2017

focus on internal gravity waves: forcings

Tides



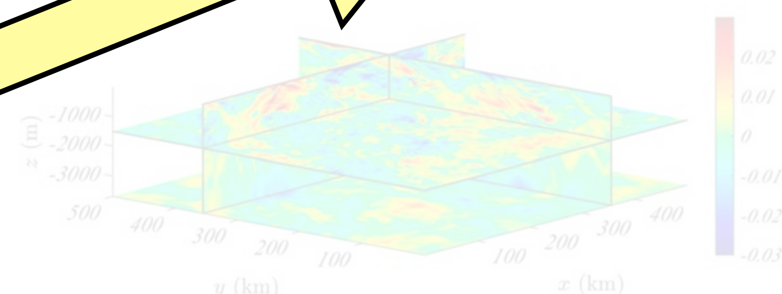
Klymak et al. 2012



Winds

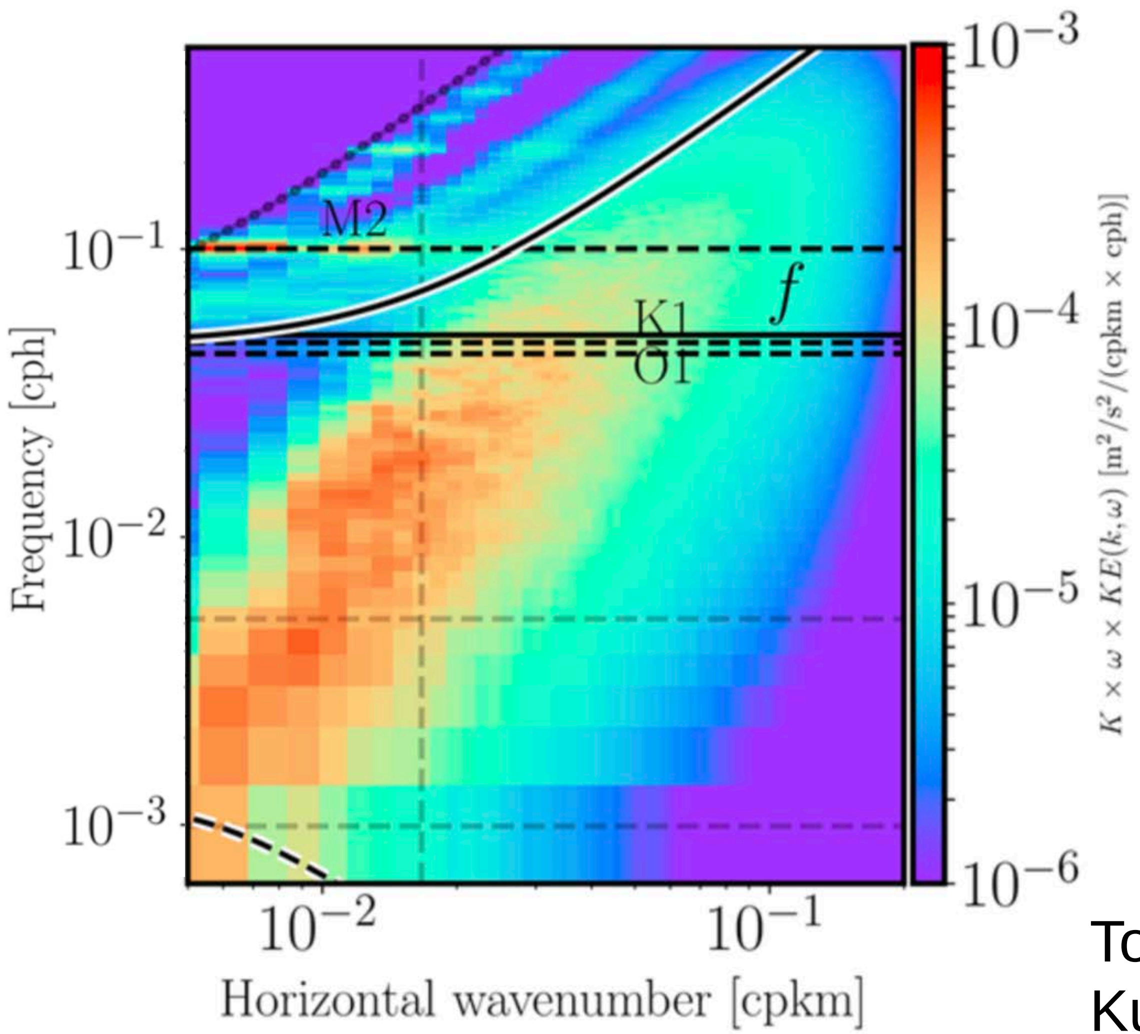
the “continuum”

Balanced flow



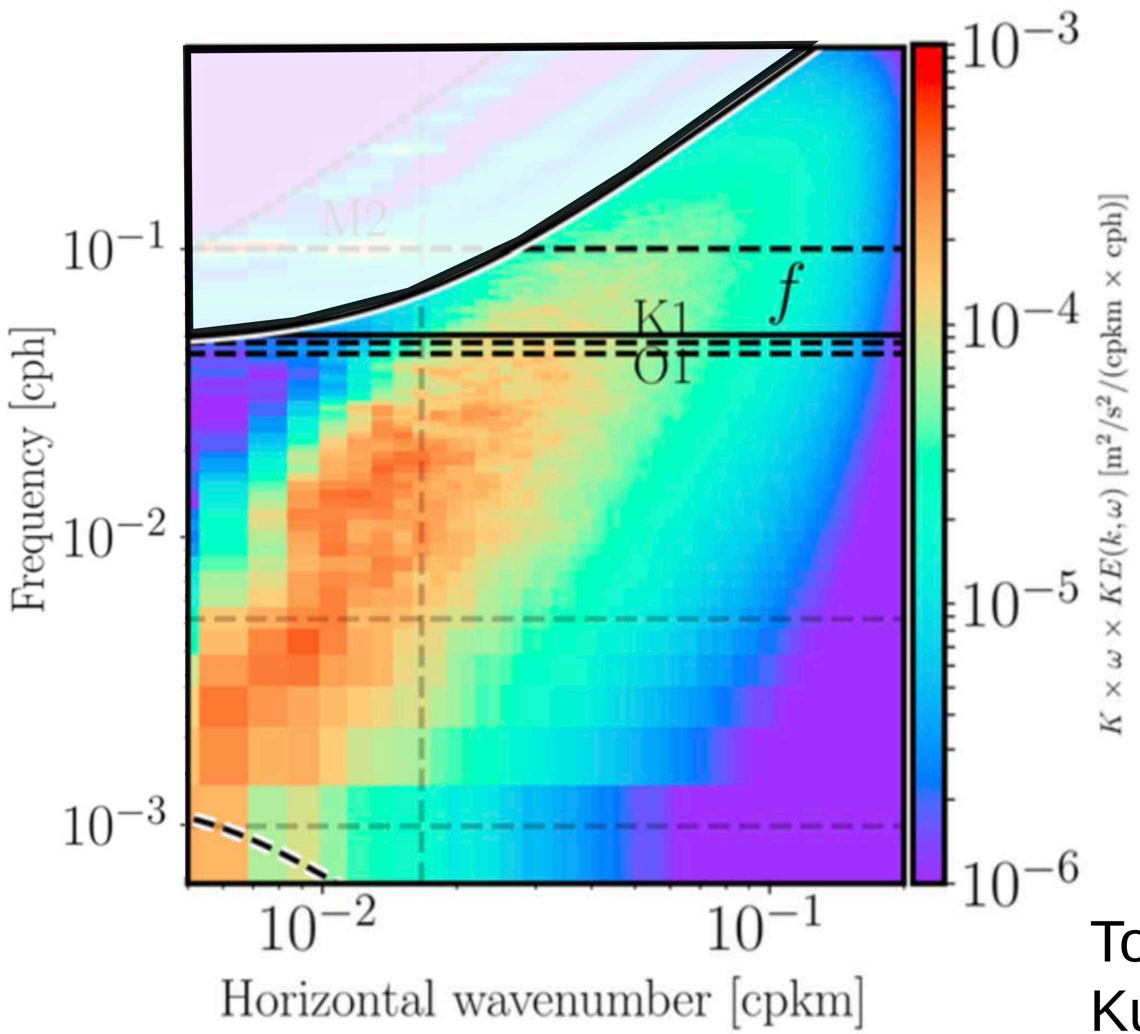
Shakespear and Hogg 2017

in spectral space



Torres et al. 2018
Kuroshio ext.

in spectral space



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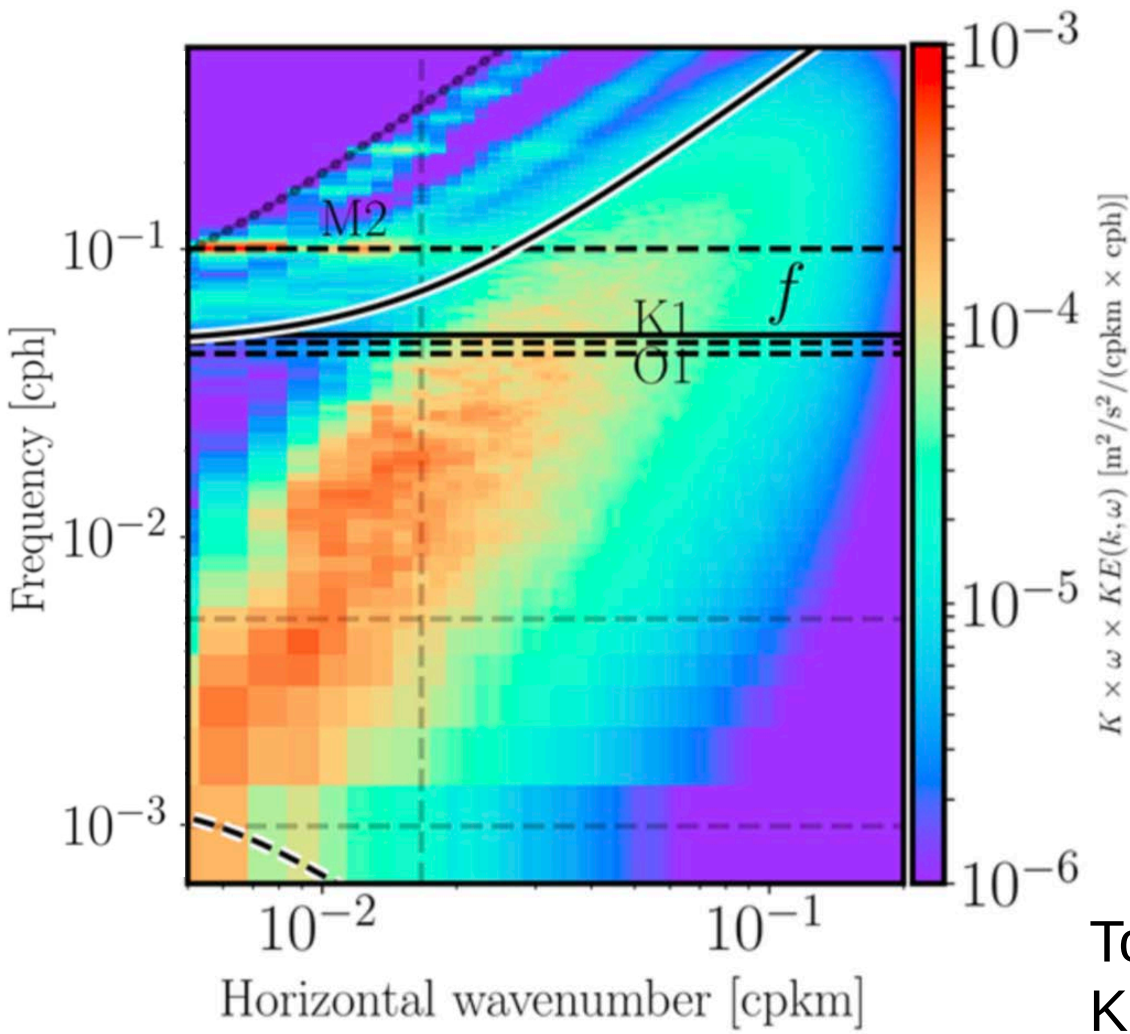
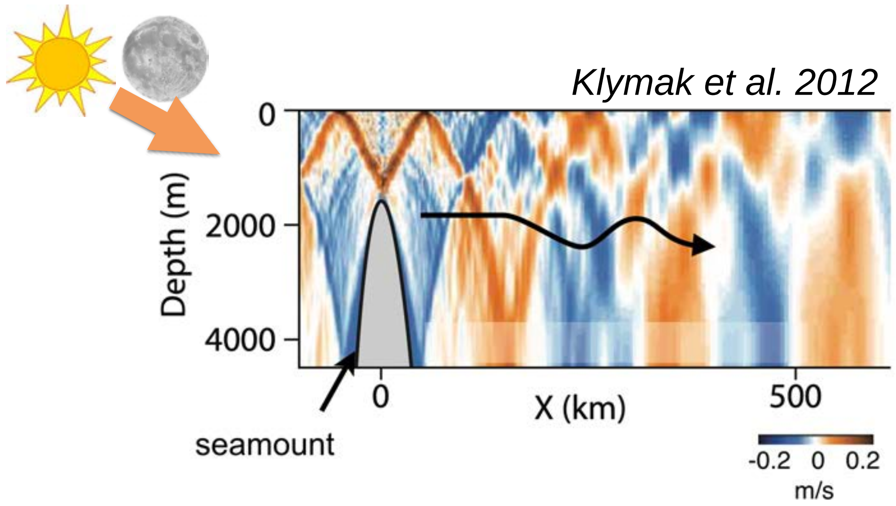


Torres et al. 2018
Kuroshio ext.

- this can only be computed from numerical simulation outputs
- diagnostics used to define transition length scales between IGW and balanced motions (Qiu et al. 2018)
- here: method when temporal and/or spatial resolutions are limited

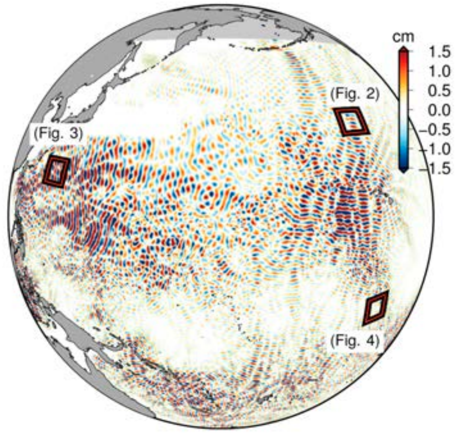
internal tides



known forcing: frequency / generation

only part of IGW motions that can be captured by SSH solely

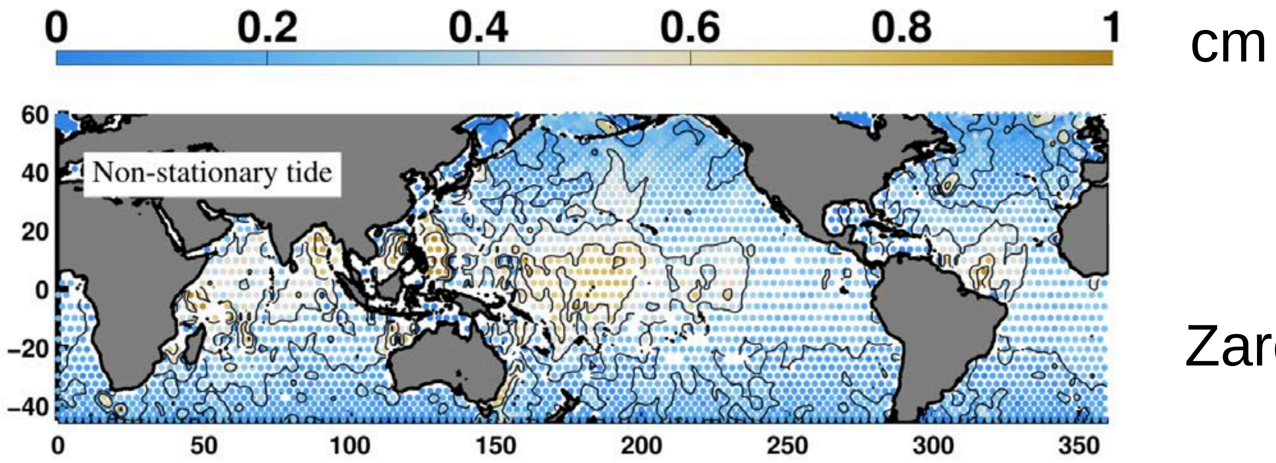
stationary internal tide



Zaron 2019

- harmonic analysis: Ray and Zaron 2016
- + dispersion relation: Zhao 2016, Zaron 2019
- simultaneous mesoscale/IT projection: Ubelmann WIP
- dynamics: Kelly et al. 2016, Egbert, Dunphy et al. 2016
  Maybe not accurate enough for phase
  Sufficient knowledge of parameters (stratification, topography)?
  Improved formulation?
- full realistic models: kind of the same

nonstationary internal tide



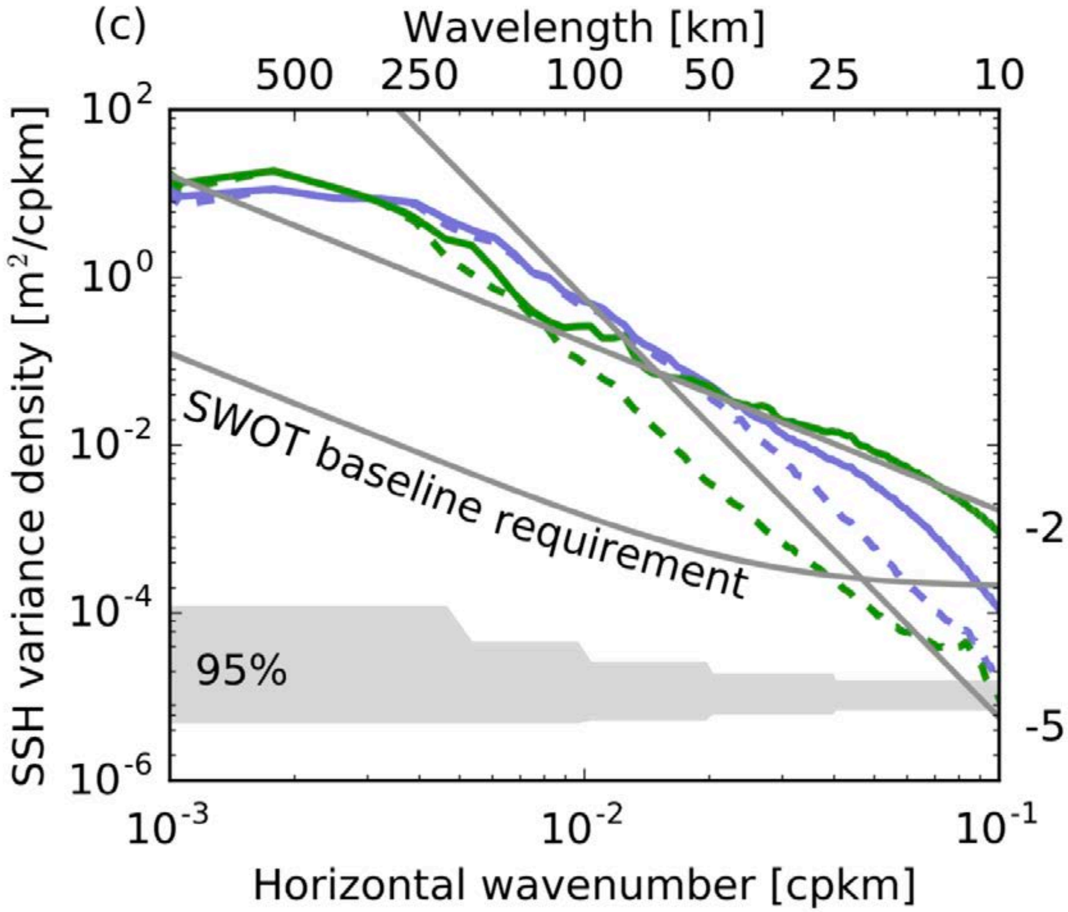
Zaron 2016

- weaker but key for our understanding of the internal tide life cycle
- energy left-over after removing the stationary part (mode 1 wavenumber): Ray and Zaron 2016
- seasonal variability, follows dispersion (Ray??)
- dynamical models (Kelly et al. 2016, Dunphy et al. 2016):
    - may have accuracy issue: models + knowledge of slow flow
    - phase vs amplitude
- combinations with other datasets: drifters, gliders, moorings
- realistic models? other way around: use estimate of nonstationary tide to calibrate them

the continuum

still focusing on SSH …

Leveraging canonical wavenumber distributions:



Rocha et al. 2016

Vergara et al.??

+ Torres et al. on going?

Limitation: “only” quantify magnitude of largest contributor

Some regions do not exhibit such transition: see Sarah’s talk yesterday

data synergies: ship-track velocity, u(x) v(x)

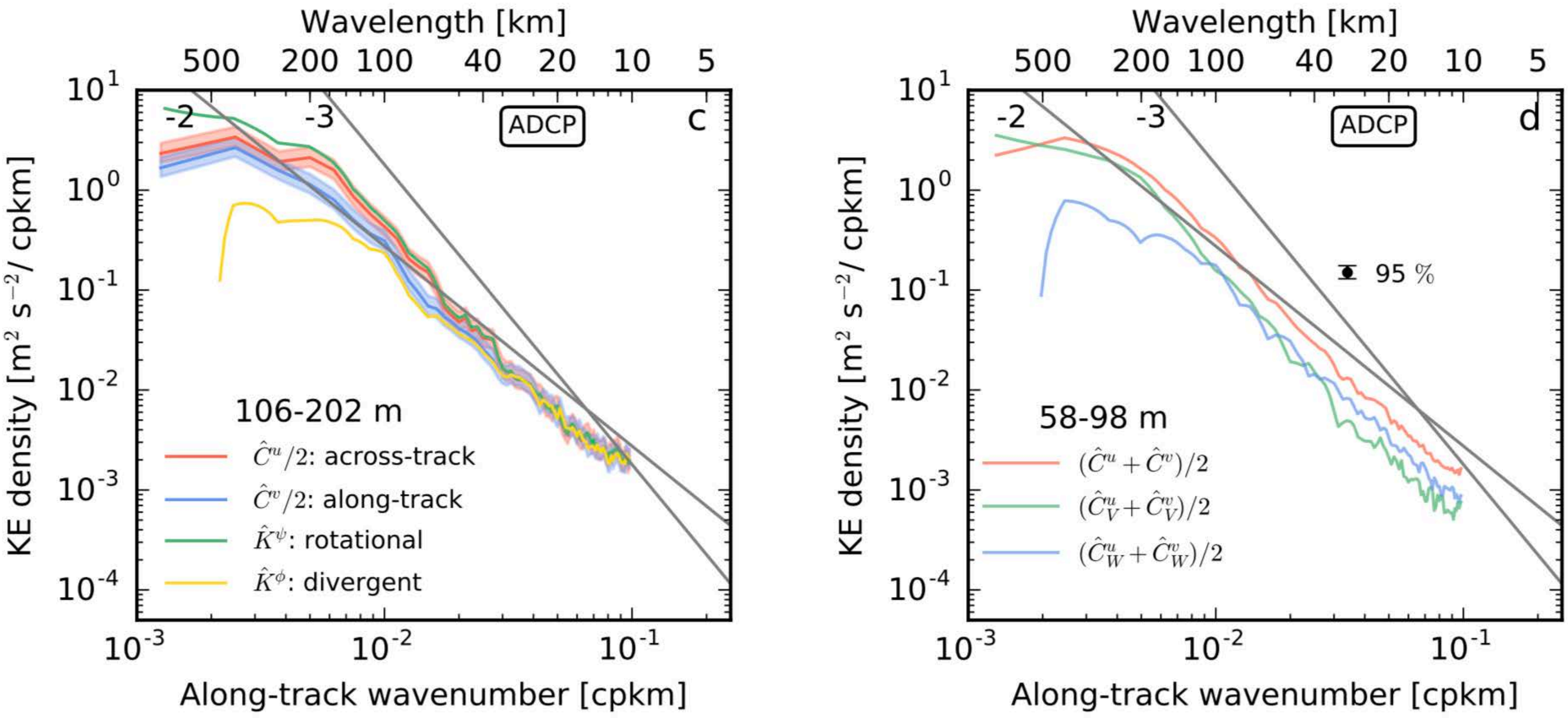
looking at other fields …
in situ data: see Kyla's yesterday morning, notably for gliders

Buhler et al. 2014, 2017
Helmholtz decomposition:
rotational = balanced + igw / divergent = igw
Assumptions: stationarity, (isotropy), igw energy equipartition
Relevant for the continuum
Leads to one-dimensional wave spectra of rotational and divergent
With additional assumptions, leads to balanced and igw spectra (u,v):
igw follow Garret-Munk, along-track knowledge of density

Put into practice multiple times: Buhler et al. 2014, Callies et al. 2014, Rocha et al. 2015, …

not phase resolving
open question: apply similar tools with a 2D pressure field

data synergies: ship-track velocity, u(x) v(x)

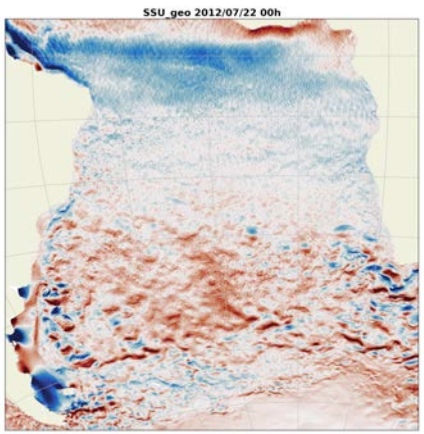


Rocha et al. 2015, Drake passage

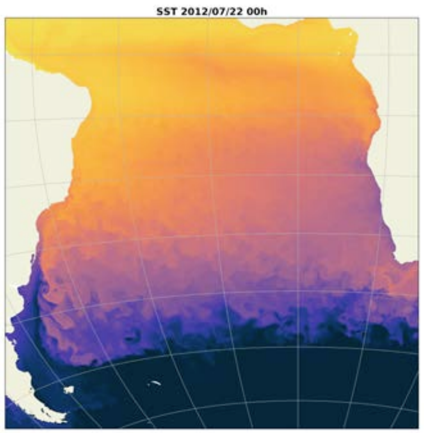
not phase resolving
open question: apply similar tools with a 2D pressure field

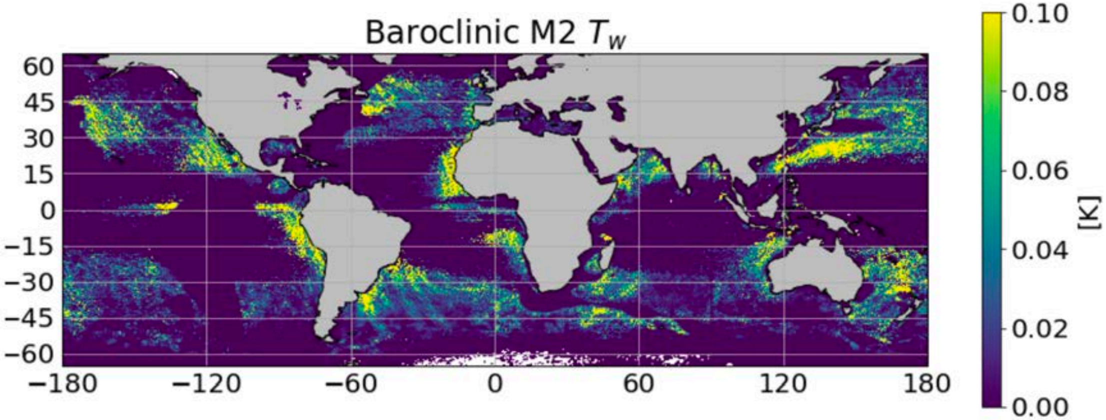
tracers

U



SST



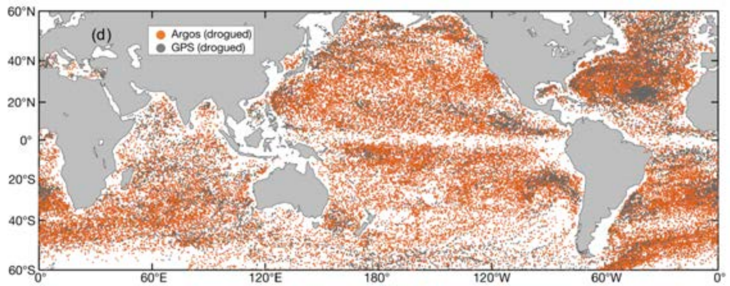


Haro-Gonzalez et al. to be submitted

weak igw variability on tracers
challenges:
- Data availability (infrared SST, optical)
- Difficult to make SSH and SST talk together (Haussman and Czaja 2012, eSQG litterature)

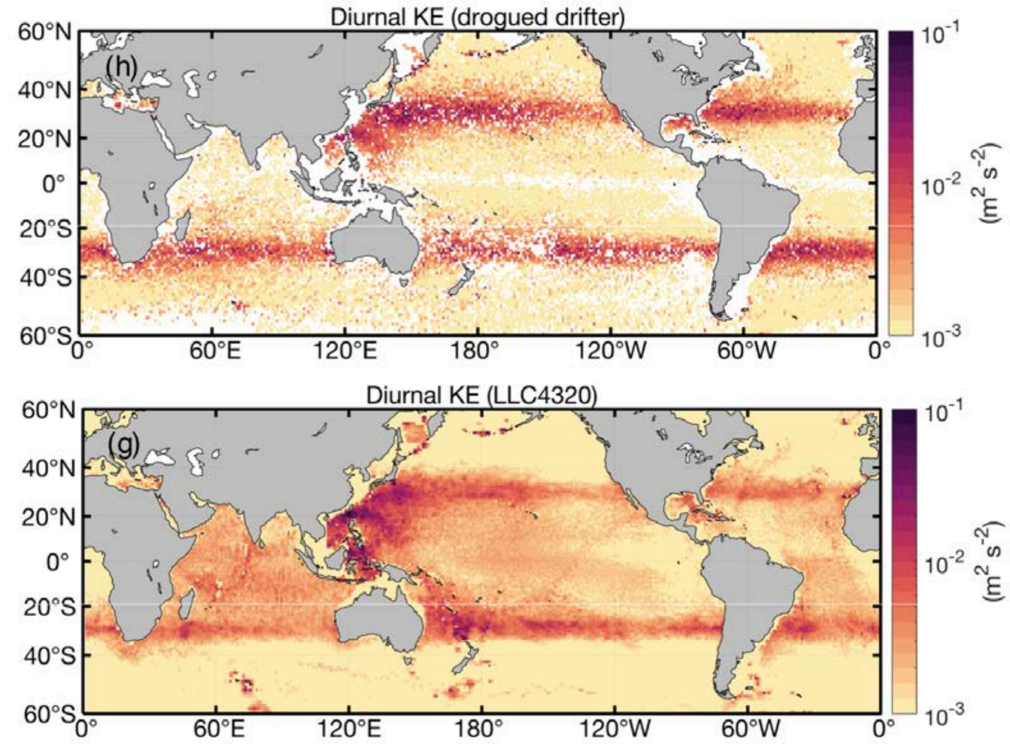
More work required:
- conservation equations of tracers of momentum (X. Yu)

other synergies: surface drifters



Yu et al. under review
GDP hourly database
collab. with Shane Elipot (a. o.)

See also variance reduction in
Zaron 2019



interesting challenges:
- extract wave information along Lagrangian trajectories

technical questions:
- appropriate ways to simulate trajectories in numerical simulations (interpolation orders and model output frequencies)

… PhD starting in Fall, next SWOT proposal

DYNAMICS

- dispersion / polarization relationships (incl. non-divergent)
- canonical spectral distributions
- equations of evolution

FORCING

- frequency
- geographical distribution

OBSERVABLES

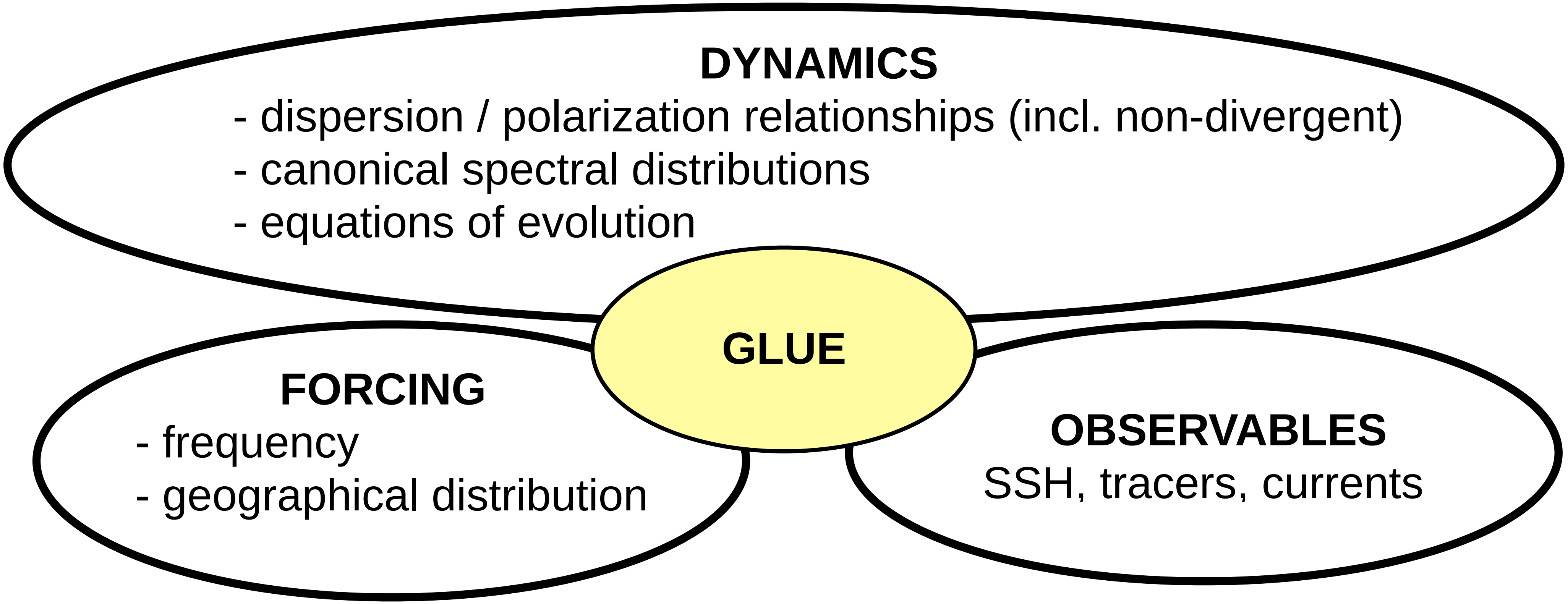
SSH, tracers, currents

different disentanglement outcomes:

- bulk parameters, for ex. relative energy levels, wavenumber distributions
- vs phase resolved estimations (operational applications)

multiple ways to define/project motions onto balanced/unbalanced contributions: more work needs to done about each other relates
No unified approach

synergies: promising, more to explore, systematic vs scenes



different disentanglement outcomes:
- bulk parameters, for ex. relative energy levels, wavenumber distributions
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multiple ways to define/project motions onto balanced/unbalanced contributions
- no unified definition nor approach, observables often drive methods
- more work needs to done about each other relates

synergies: promising, more to explore, systematic vs scenes