Lake Geneva:
A natural laboratory for transport processes

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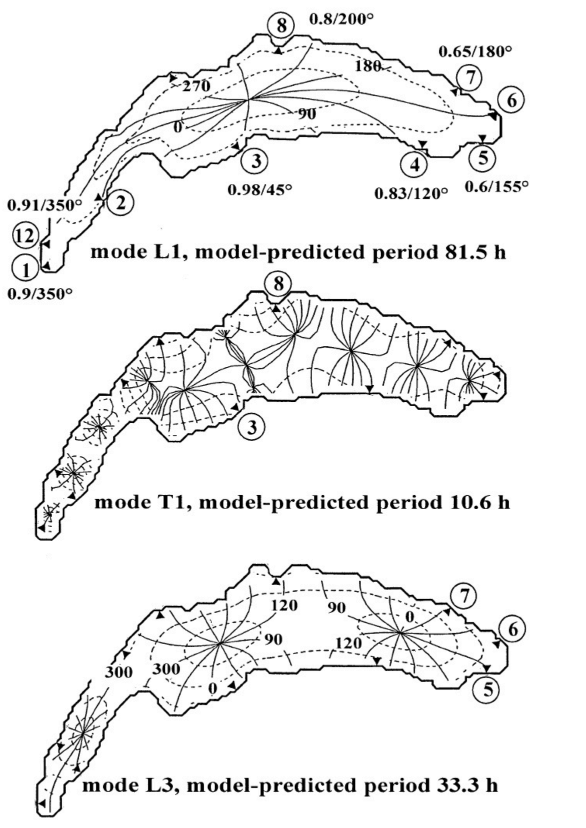
Lake Geneva

- Largest freshwater body in Western Europe
- Area of 580 km², 73 km long, 14 km wide
- Maximum depth of 309 m, mean depth of 152 m
- Important regional freshwater resource
- Densely populated region
- Long residence time, polluted inflows

Linear dynamics



- Density stratified throughout the year
- Coriolis force dominates the dynamics
- Wind is the main forcing
- Unknown full mechanical energy budget
- Steep slopes (particularly in the east)

Response to wind forcing is usually interpreted in terms of linear "seiches", i.e. linear, long internal waves:

- Mode 1 and 3 Kelvin wave (L1, L3)
- Mode 1 Poincaré wave (T1)
- Free near-inertial motions

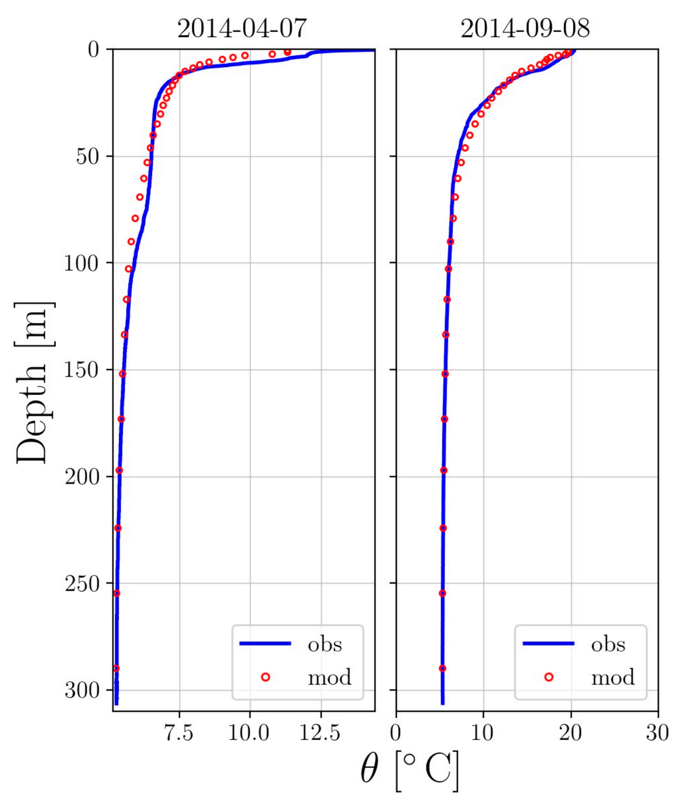
Bauer et al. (1981), Bauerle (1985), Lemmin et al. (2005)

These motions are to some extent analogues of tidal motions in the ocean, but are markedly less energetic than tides: typical velocities are of the order of 1 cm s^{-1}.

Vertical mixing in a numerical model

3D numerical model of the lake using MITgcm code. Both hydrostatic and non-hydrostatic simulations were performed. Horizontal grids fully resolve the Rossby deformation scale, but not the lateral boundary layers. Vertical resolution is less than 1 m near the surface, coarser at depth.

Vertical mixing is parametrised using the 1 equation model by Gaspar et al. (1990) in combination with enhanced diffusivity under unstable stratification for hydrostatic simulations. This overly simple approach provides remarkably good results, in particular during summer (strong stratification).

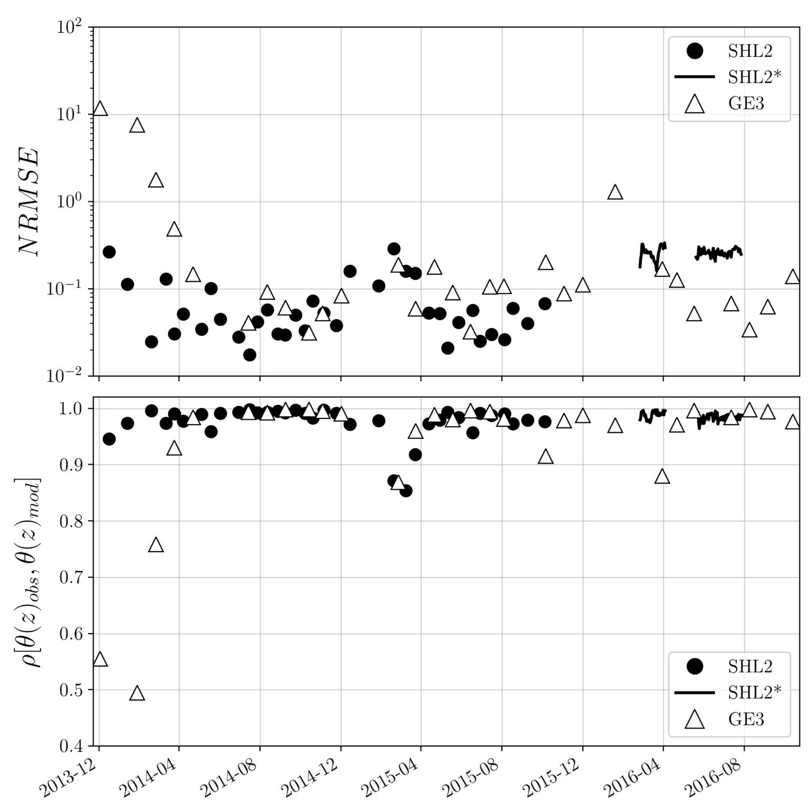


Systematic validation of model stratification against monthly temperature profiles:

$$NRMSE = \frac{\langle(\theta_{obs} - \theta_{mod})^2\rangle^{1/2}}{\max[\theta_{obs}] - \min[\theta_{obs}]}$$

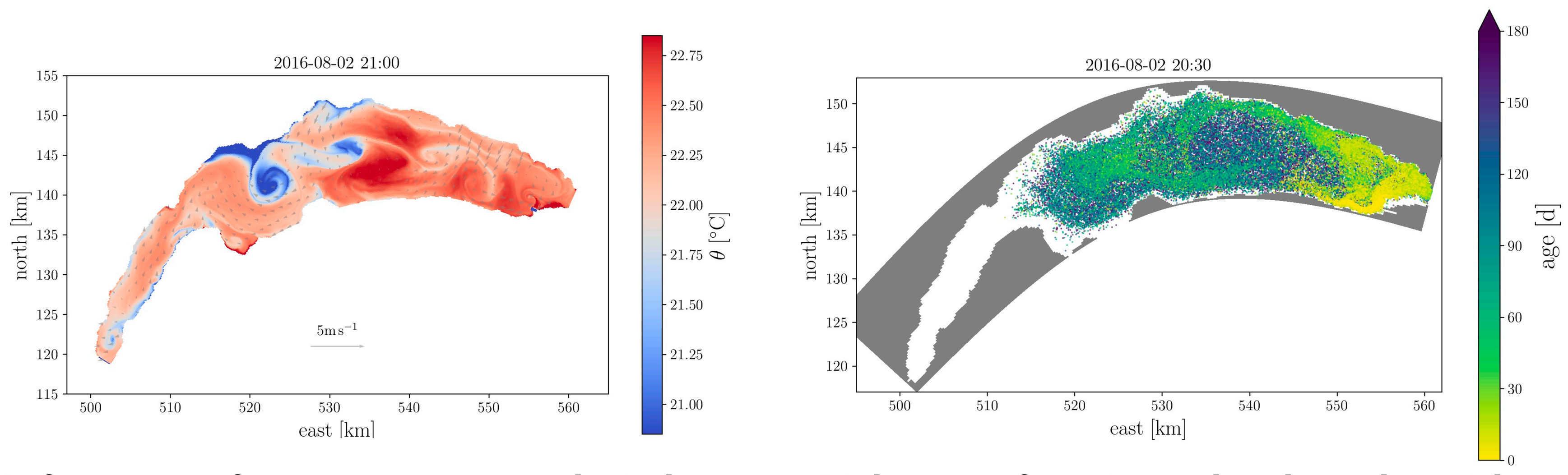
$$\rho[\theta_{obs}, \theta_{mod}] = \frac{\langle \Delta\theta_{obs}\, \Delta\theta_{mod}\rangle}{\langle \Delta\theta_{obs}^2\rangle^{1/2} \langle \Delta\theta_{mod}^2\rangle^{1/2}},$$

with $\Delta x = x - \langle x \rangle$



Is that all there is?

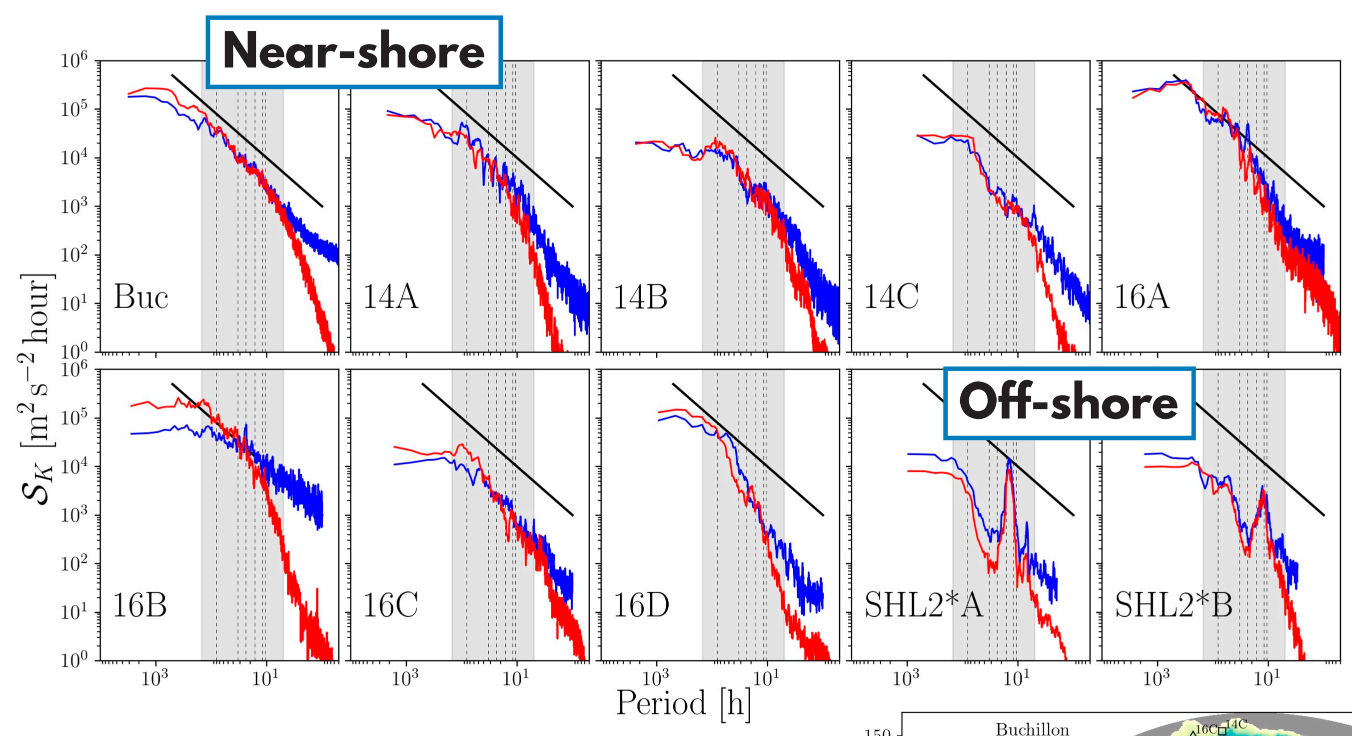
If large scale motions were perfectly linear and steady, there would be no cross-shore transport (Taylor–Proudman theorem), except for small scale turbulent mixing. Numerical models, for instance, suggest otherwise:



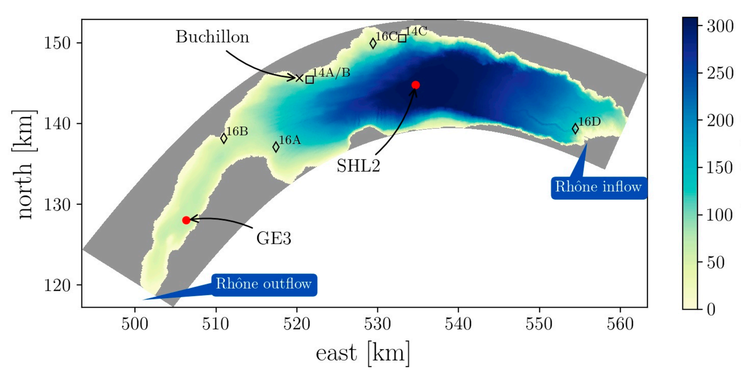
Left: near-surface temperature and wind vectors. Right: age of continuously released particles.

- What drives the dispersion of tracers?
- Are nonlinear dynamics important?
- Is there a link between linear seiches and nonlinear motions?
- Is there a link between horizontal dispersion and vertical mixing?

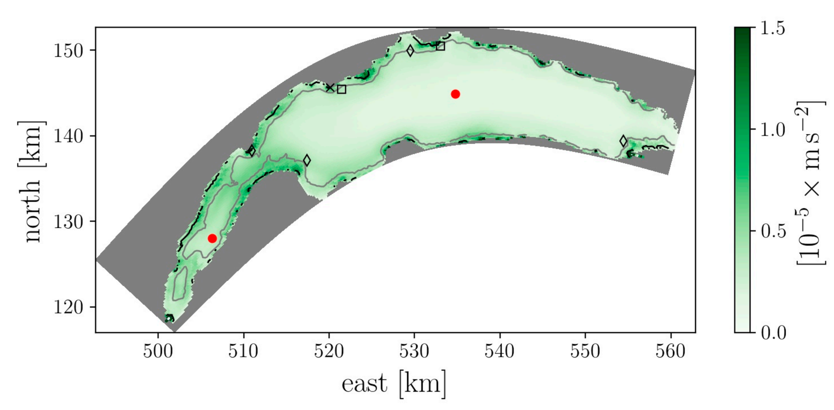
Nonlinear dynamics and bottom friction



Kinetic energy spectra from observational and model data. The vertical lines mark, from left to right, the following periods in hours: 81.5 (L1), 33.3 (L3), 24 (diurnal), 16.5 (inertial/Coriolis), 12 (semidiurnal) and 10.6 (T1). The thick black line is a guide for the eye (power law with exponent -1). The gray shaded area approximately identifies the internal wave range.



Nonlinear advection and dissipation in the numerical model:



Green shading: advective component of acceleration. Contours: forcing minus dissipation (mainly bottom friction). Gray (black) contours: 10^{-6} (10^{-5}) m s^{-2}. Average over the period from 2016-07-01 to 2016-09-30, using bihourly averaged diagnostics.

Conclusions and outlook

- A simple turbulence model reproduces the observed stratification.
  - Do we need better models or are uncertainties elsewhere?
- Linear seiches contribute negligibly to near-shore kinetic energy.
- Nonlinear motions near-shore are closely connected to bottom friction.
- What is the nature of these nonlinear motions?
  - Waves? Turbulence? Boundary current instabilities (Brink, 2016)?
  - How do they change horizontal dispersion?

References

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