Turbulent Structure underneath Air-Sea Wavy Interface: Large-Eddy Simulation

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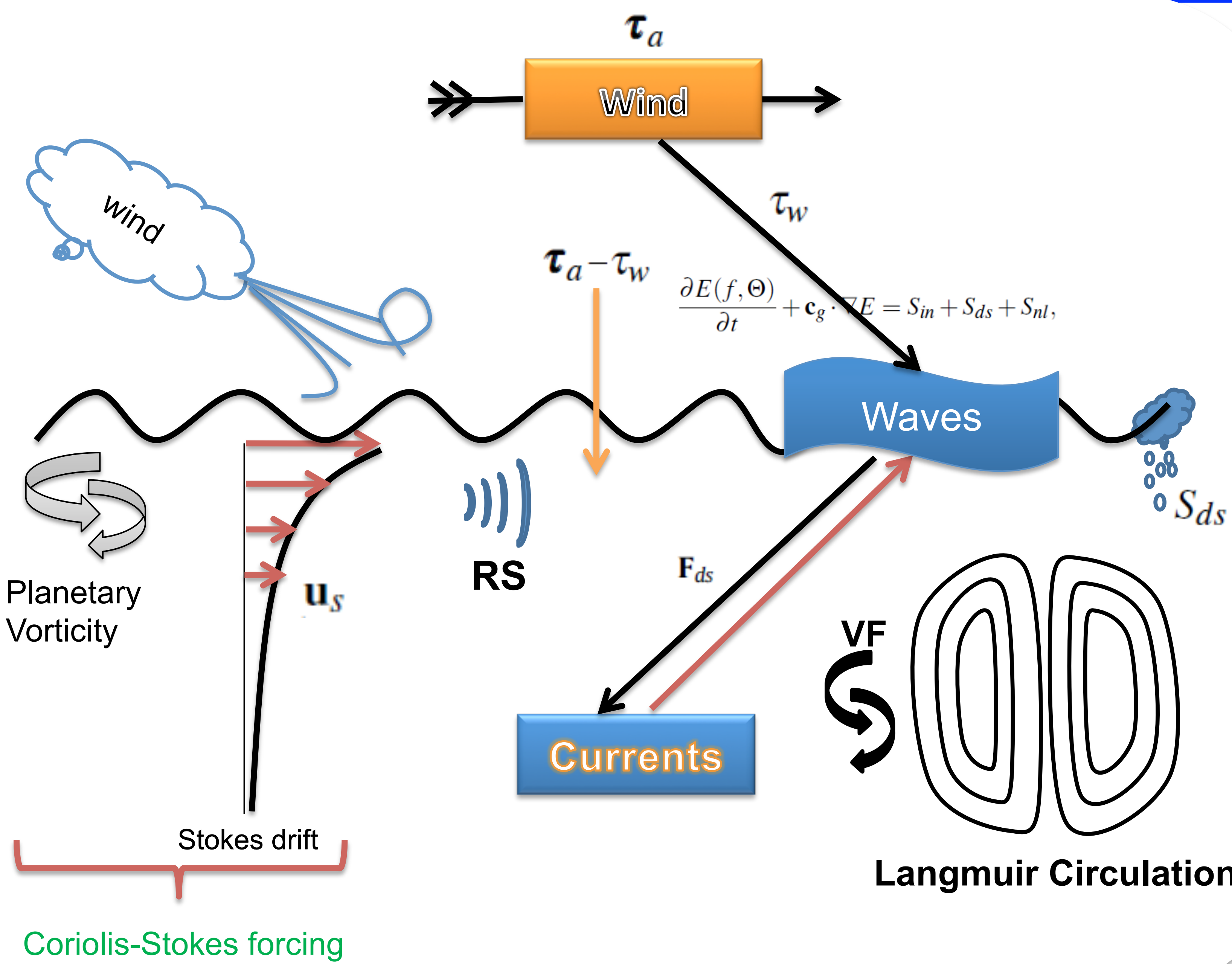
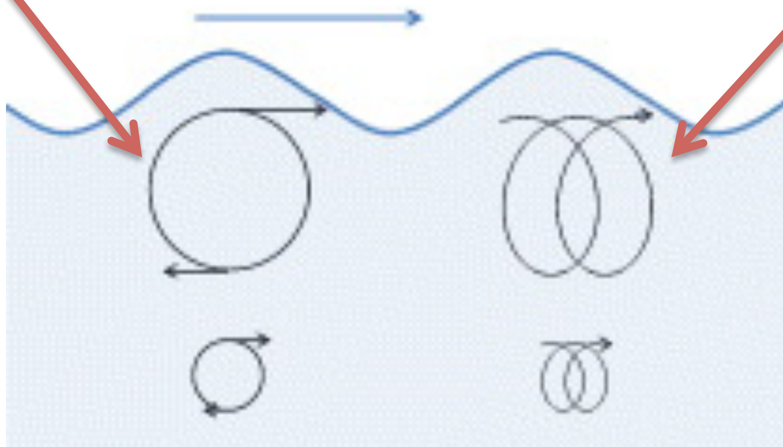
Introduction

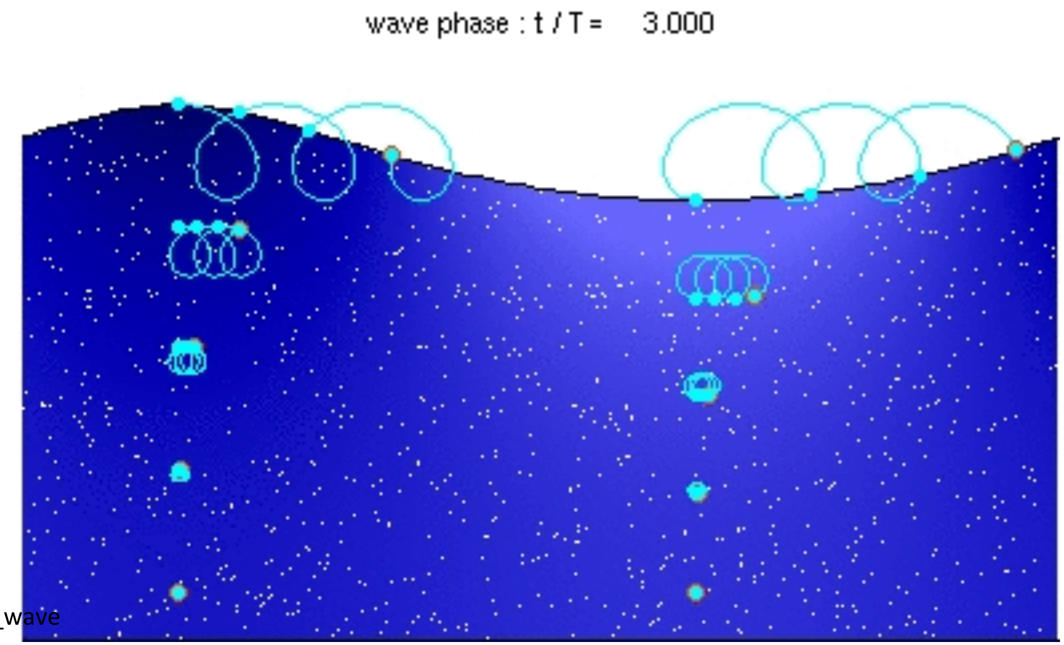


Stokes drift

Linear wave theory

Nonlinear wave theory

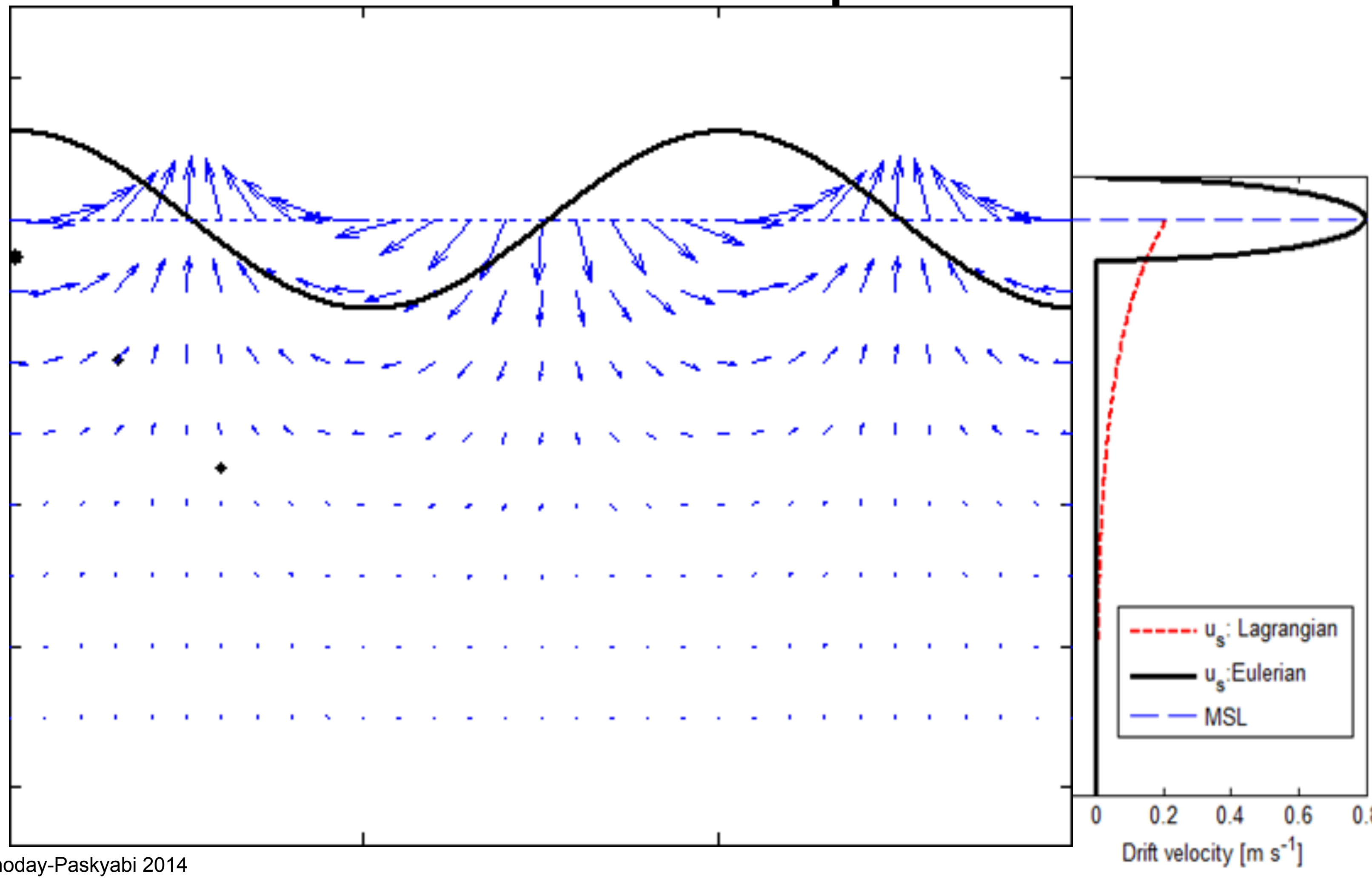




http://en.wikipedia.org/wiki/Wind_wave

Stokes drift

1. Lagrangian description
2. Eulerian description



From Bakhoday-Paskyabi 2014

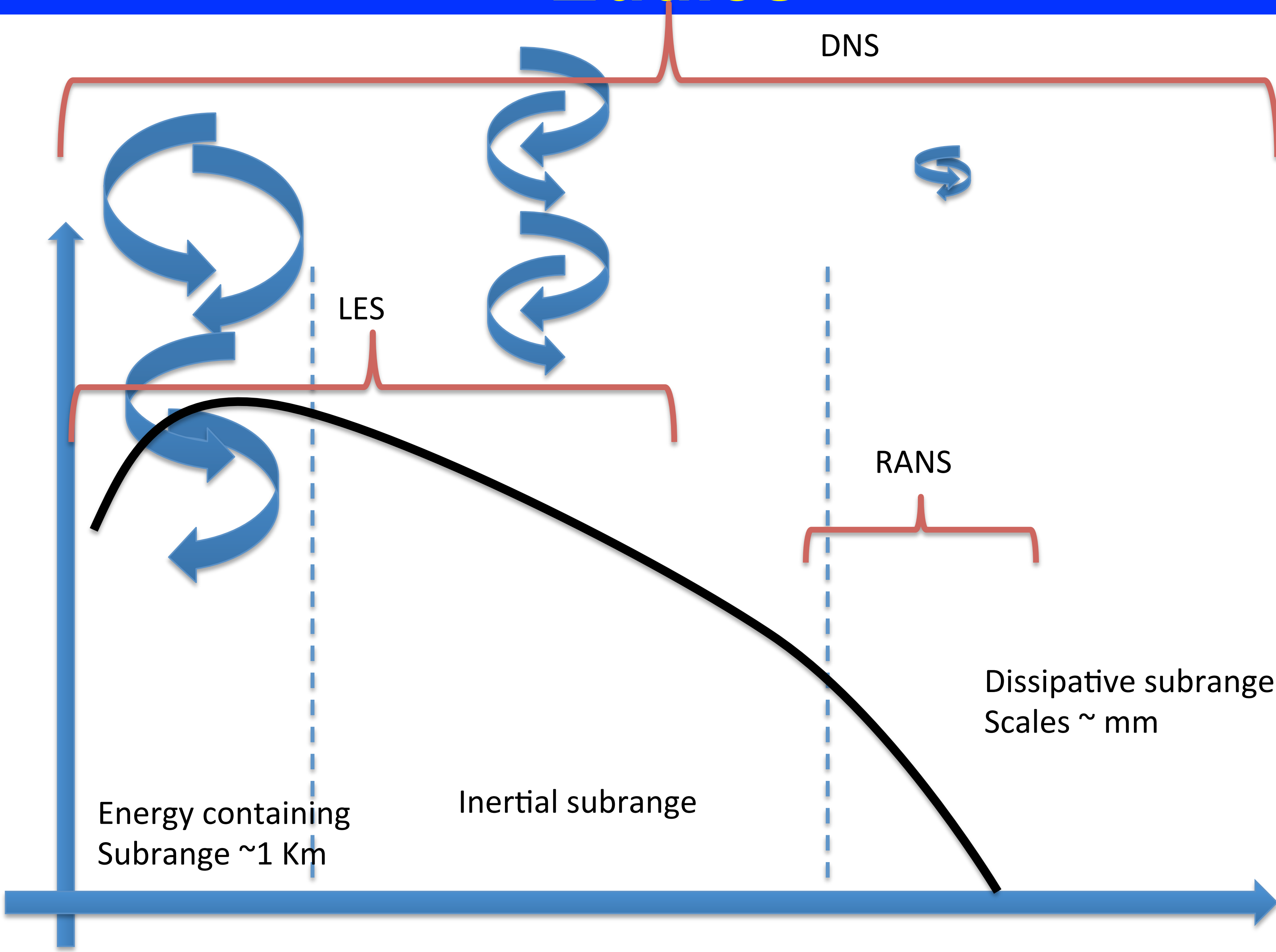
Turbulence (compressible flow)

- Reynolds Averaged modelling (RANS)
- capture only the ensemble statistics

- Direct numerical simulation (DNS)
  capture all eddies

- Large eddy simulation (LES)
  intermediate method

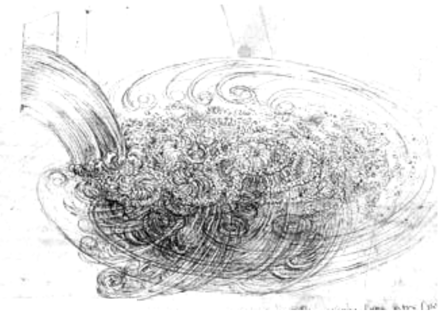
Eddies


DNS
LES
RANS
Energy containing
Subrange ~1 Km
Inertial subrange
Dissipative subrange
Scales ~ mm

Wave-tubulence interaction (RANS)

Decomposition

Eulerian frame



$$T' \ll \tilde{T} \ll \bar{T}; \text{ and } X = X' + \tilde{X} + \overline{X},$$

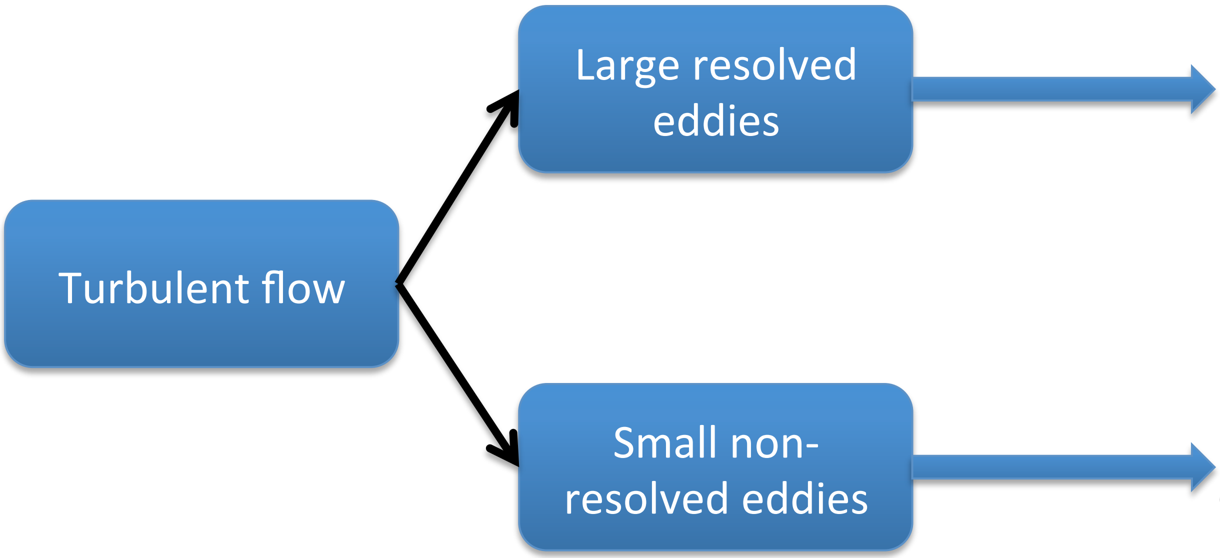
$$u = \overline{u} + u'$$
$$p = \overline{p} + p'$$

$$\overline{u'} = 0$$
$$\overline{\frac{\partial u}{\partial t}} = \frac{1}{T}\int_0^T \frac{\partial u}{\partial t}\,dt = \frac{u(T) - u(0)}{T}$$

$$\frac{\partial u}{\partial t} = -\frac{\partial(\overline{u'w'})}{\partial z} + f_{\mathrm{cor}}(v + v_{\mathrm{s}}) + F_x,$$
$$\frac{\partial v}{\partial t} = -\frac{\partial(\overline{v'w'})}{\partial z} - f_{\mathrm{cor}}(u + u_{\mathrm{s}}) + F_y,$$

Bakhoday-Paskyabi 2014

LES



Low pass filter

$$\tilde{f}(x) \equiv \int f(x')G(x,x')dx'$$

Subgrid scales

$$f''(x) = f(x) - \tilde{f}(x)$$

G-Filtering

$$\frac{\partial u_i}{\partial t} + u_j \frac{\partial u_i}{\partial x_j} = \frac{g_i}{T_0}\theta - \frac{1}{\rho}\frac{\partial p}{\partial x_i} + \upsilon \frac{\partial^2 u_i}{\partial x_j^2}$$

SGS

$$\frac{\partial \tilde{u}_i}{\partial t} + \tilde{u}_j \frac{\partial \tilde{u}_i}{\partial x_j} = \frac{g_i}{T_0}\tilde{\theta} - \frac{1}{\rho}\frac{\partial \tilde{p}}{\partial x_i} - \frac{\partial(\widetilde{u_i u_j} - \tilde{u}_i \tilde{u}_j)}{\partial x_j} + \upsilon \frac{\partial^2 \tilde{u}_i}{\partial x_j^2}$$

Wave-Averaged Large-Eddy Simulation

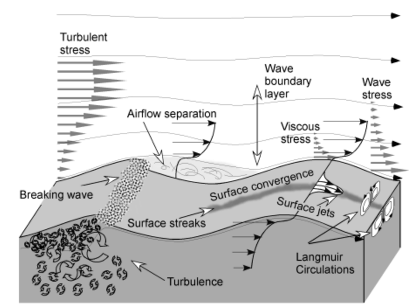
Spatially filtered and temporal filtration for wave decomposition

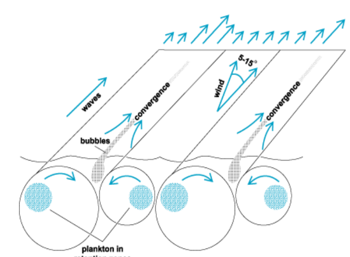
$$\frac{\partial \bar{u}_i}{\partial x_i} = 0$$

SGS LC Vortex force

$$\frac{\partial \bar{u}_i}{\partial t} + \bar{u}_j \frac{\partial \bar{u}_i}{\partial x_j} = -\frac{\partial \bar{\Pi}}{\partial x_i} + \frac{1}{Re_\tau}\frac{\partial^2 \bar{u}_i}{\partial {x_j}^2} - \underbrace{\frac{\partial \tau_{ij}^{LES\,(d)}}{\partial x_j}}_{\text{SGS}} + \underbrace{\frac{1}{{La_t}^2}\epsilon_{ijk} U_j^s \bar{\omega}_k}_{\text{LC Vortex force}}$$

$$\overbrace{\frac{\partial k}{\partial t}}^{1} = \overbrace{\frac{\tau}{\rho_0}\cdot\frac{\partial \mathbf{u}}{\partial z}}^{2} + \overbrace{\frac{\tau}{\rho_0}\cdot\frac{\partial \mathbf{u}_s}{\partial z}}^{3} + \overbrace{\overline{b'w'}}^{4} - \varepsilon + \overbrace{\frac{\partial}{\partial z}\left[\frac{\nu_t}{\sigma_k}\frac{\partial k}{\partial z}\right]}^{5} - \overbrace{\frac{\partial T}{\partial z}}^{6},$$

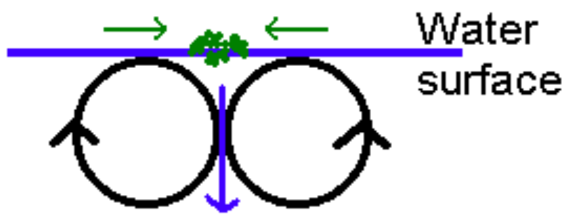




Wave-current-turbulence interaction

In coupled wave-turbulence system, Stokes drift introduces

1. **Coriolis-Stokes force and modification of momentum.**
2. **Langmuir turbulence** and enhanced/suppressed upper ocean mixing.
3. **near surface mass transport** and affecting the transport of materials and sediment transport in shallow water.



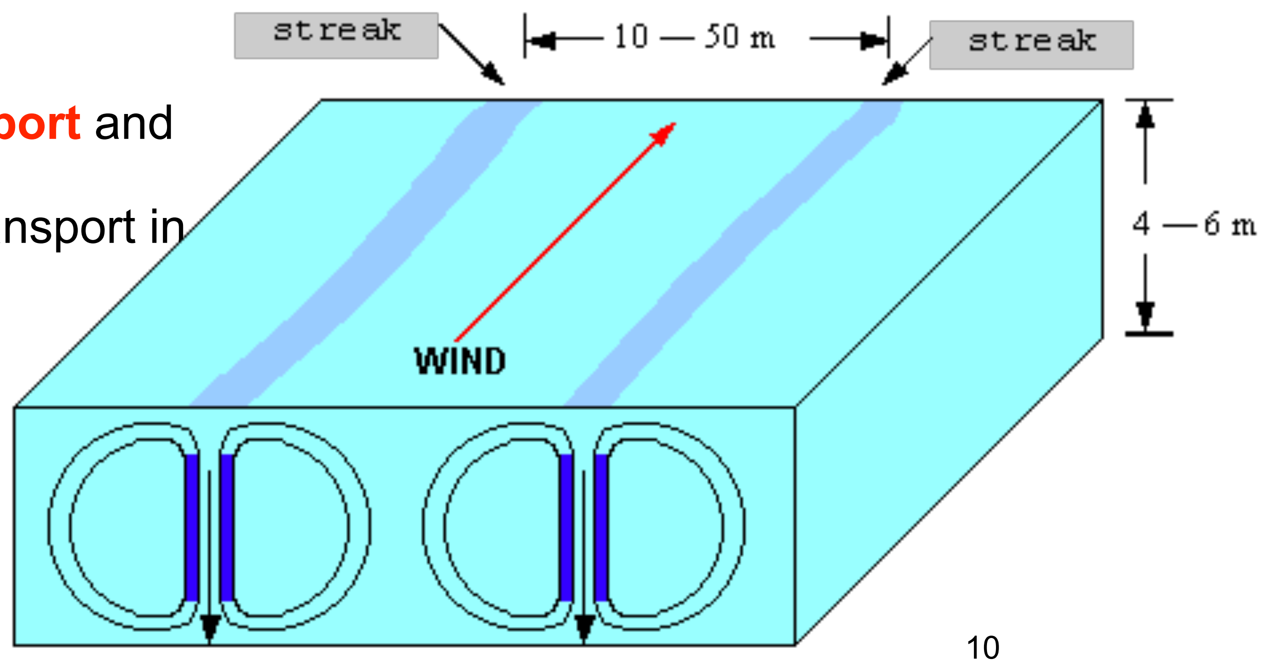
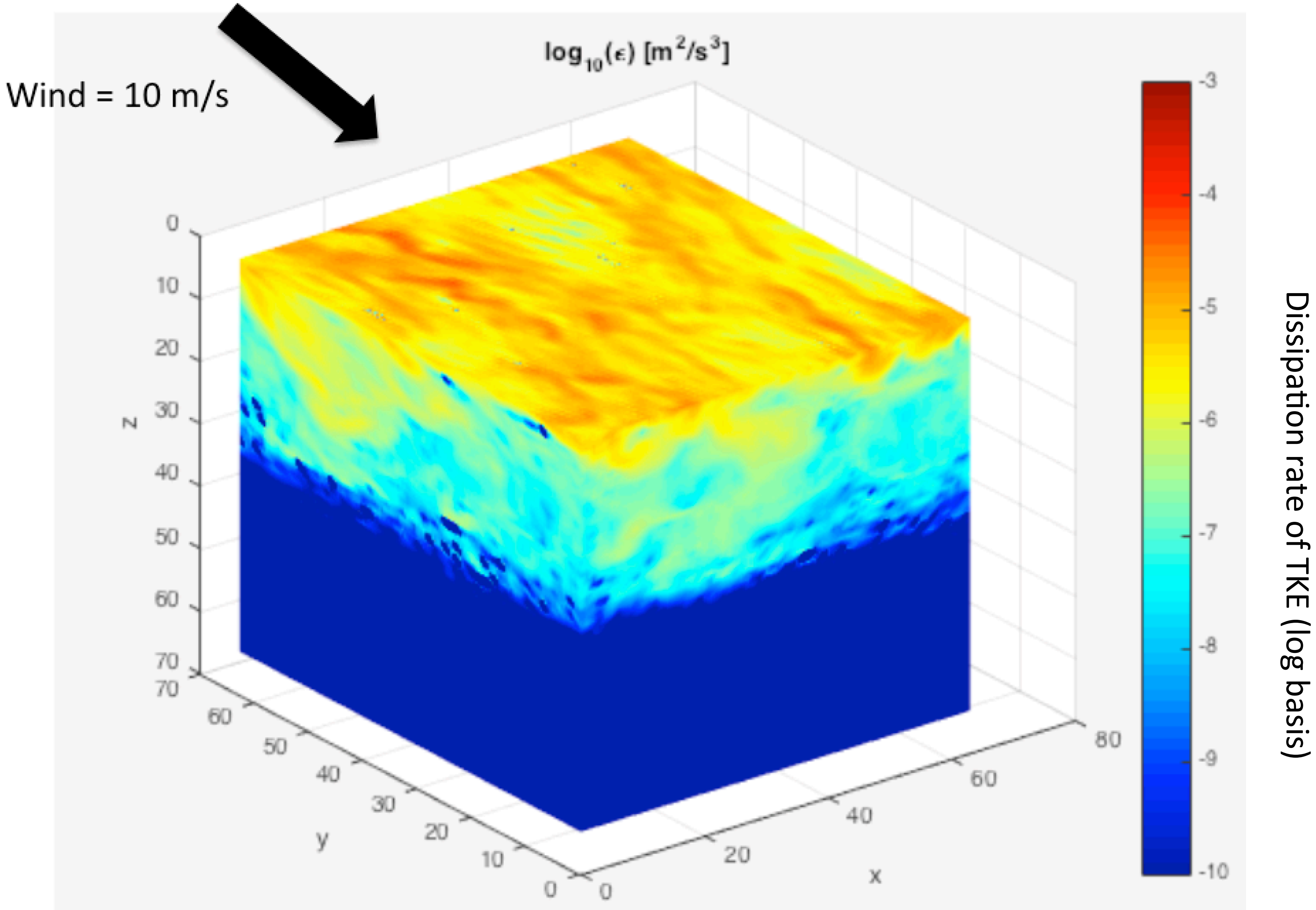


Figure 1 Diagram tracing water through Langmuir circulation cells.

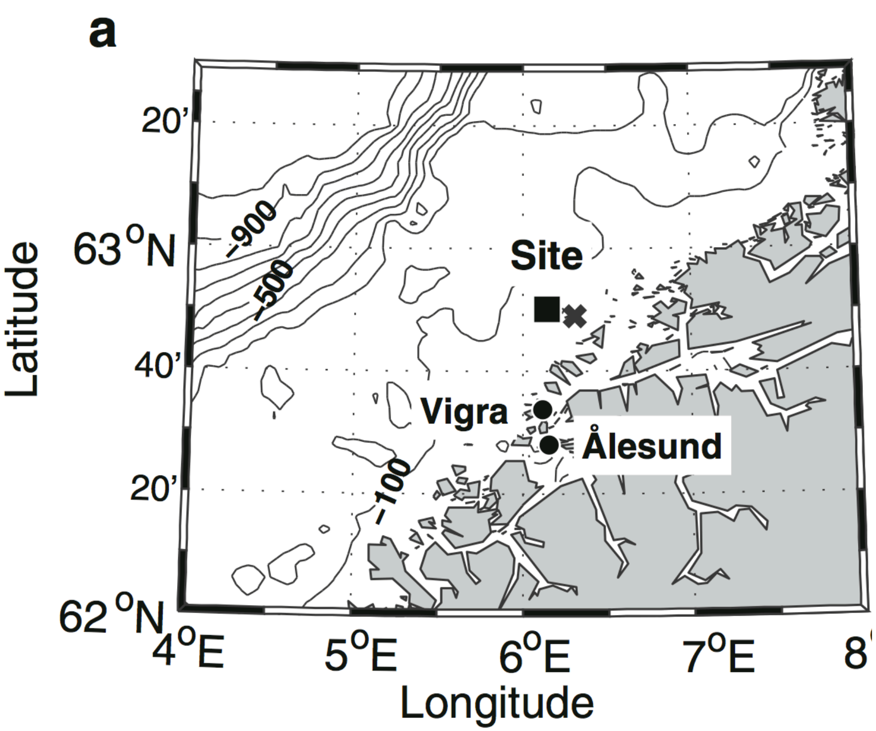
T. S. Bianchi

Example og Mixed layer Evolution

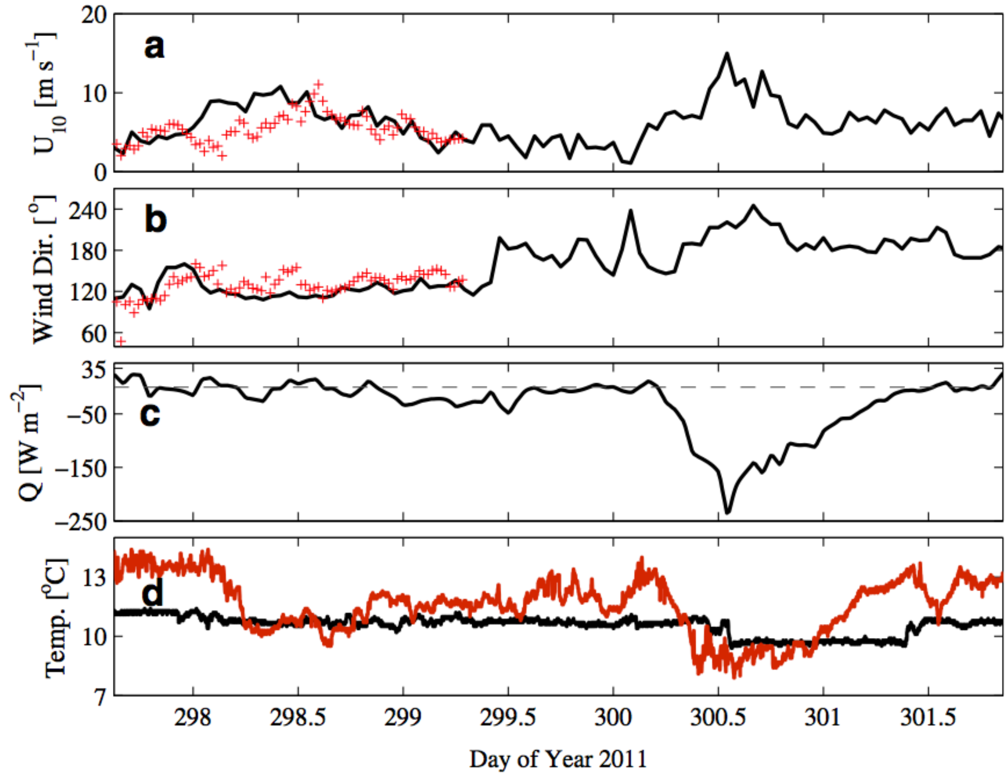


Model-Observation Assesment

Experiment site: Havsul



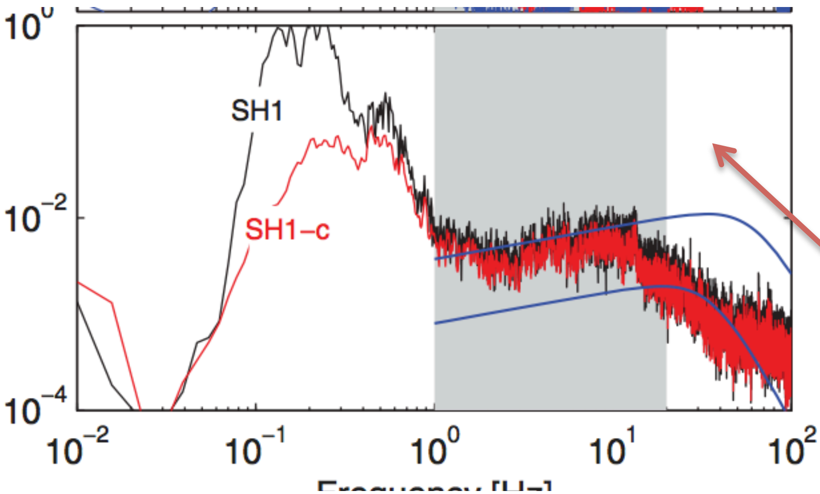
Forcing condition

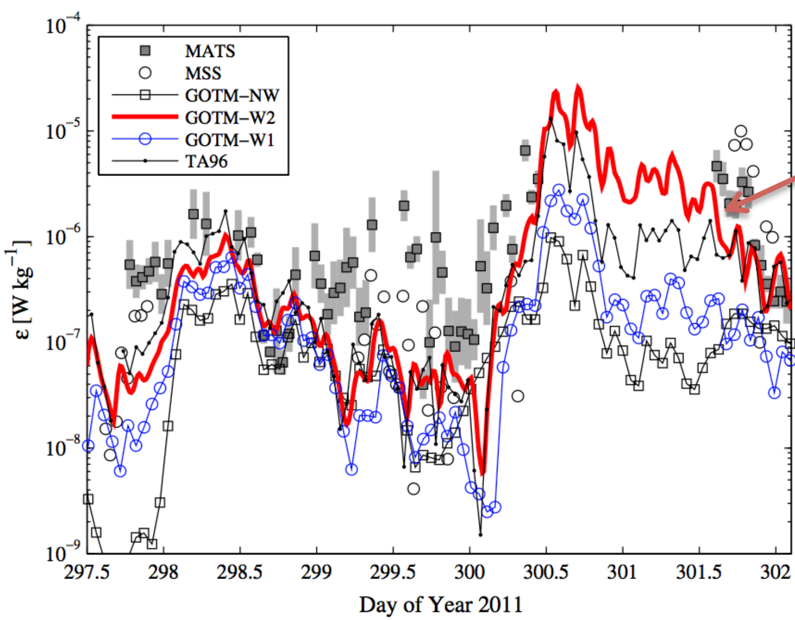


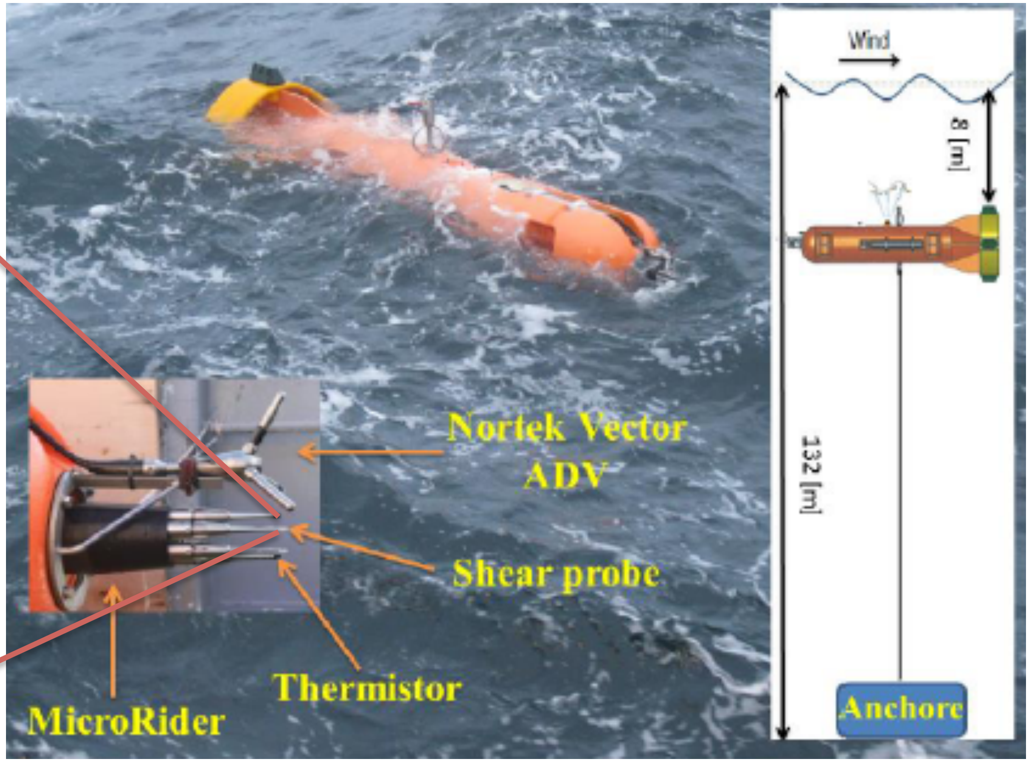
from October 25 to 30, 2011. During the field work, the wind speed ranged from 1 to 15 m s−1 with direction typically confined within from southeast and southwest from which the wind is emanating.

Model-Observation Assesment

MATS SHEAR PROBE

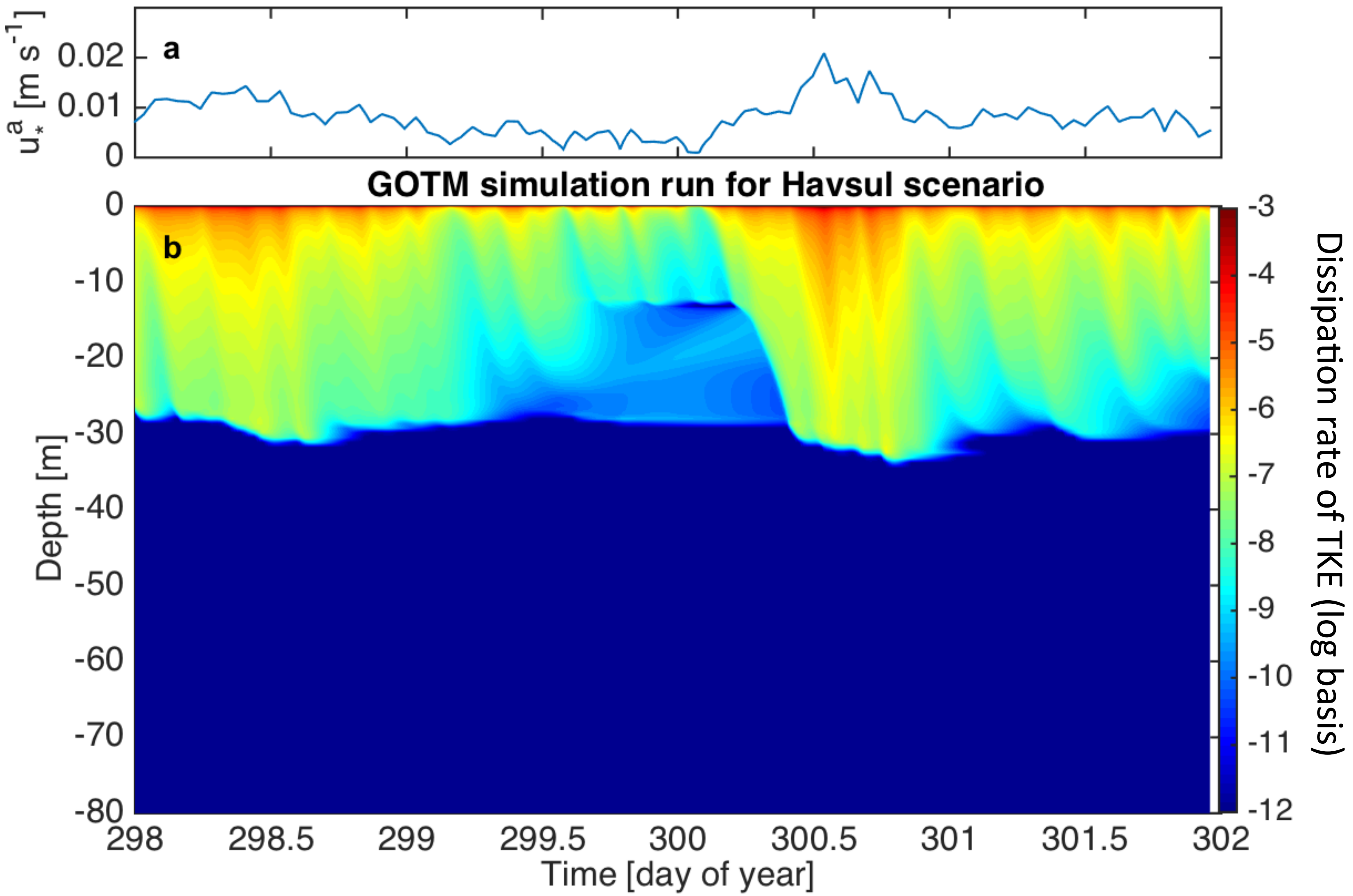




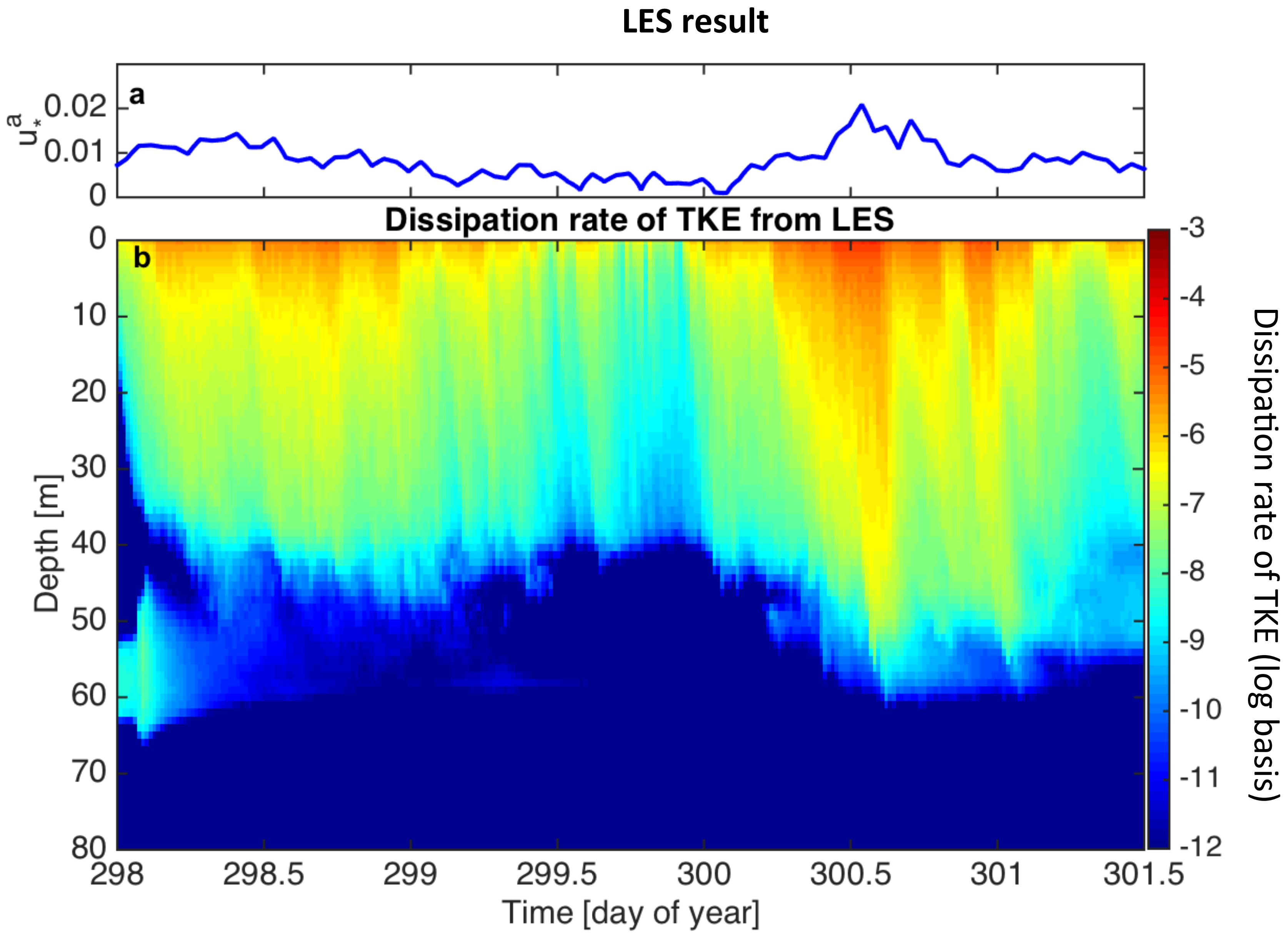


Model-Observation Assesment

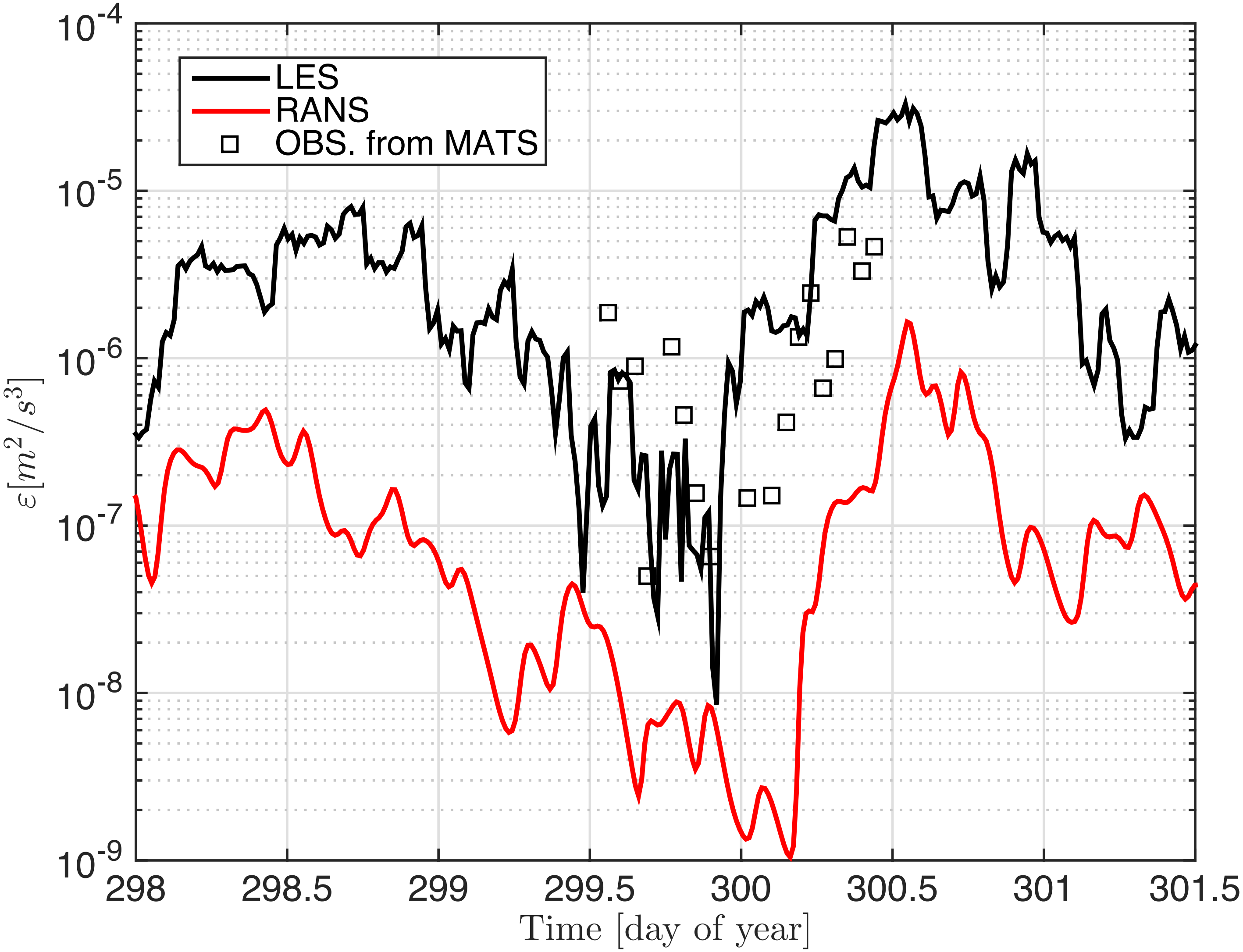
General Ocean Turbulence Model (GOTM)



Model-Observation Assesment



Model-Observation Assesment



There is a slight time-lag between GOTM & LES in this fig.

Application: Langmuir Circulation

General characterestics:

- Although depth of Langmuir cells is about 4-6 m, it can be extended up to 200 m.
- Cells spatial separation is about 10-50 m.
- The length of cells is ranged from few meters long to many kilometers.
- The cell axes are typically aligned with wind, but may vary as much as 20 degrees.
- Clles try to be aligned with wind and in the case of wind change of direction, they need 15-20 minutes to be aligned in new direction.
- Downwelling velocitties are important for mixed layer implications, biological systems, and particle tracking.
- The mixed layer can be deepend (up to 200 m) in the presence of LC.
- The LC effects can be remained still strong from a few minutes to several hours after cells develop.
- To generate LC, Wind speeds must typically reach 3 m/s.

Conclusions

1. LES gives promising estimate of turbulent fluxes near the wavy surface.
2. The closure problem in LES needs further investigation.
3. Wave breaking inclusion using dissipation source term will be included.

Acknowledgment

Author of this work is grateful of **Joachim Reuder**, **Alastair D. Jenkins**, **Ilker Fer**, **P. Sullivan**, **Ramsay Harcourt**, **J. Liang, and Martin Flugge** for all their supports and help throughout this investigation.

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