

Near-surface wind and wave drift currents in the coupled air-sea boundary layer

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Initial project goals:

- Compute and analyze global statistics of near-surface wind and wave drift from recently proposed equilibrium-sea model (Samelson 2022, JPO) .
- MERRA-2 reanalysis winds.
- Motivation: Contribute to risk reduction for ODYSEA satellite Doppler scatterometer by improving quantitative characterization and physical understanding of near-surface currents driven by wind and waves.

Future work:

- Test equilibrium-sea drift model (e.g., drogued/undrogued buoys).
- Extend coupled modeling (talk #2)

History....

- DopplerScatt: Bragg scattering from capillary waves (cm) **initially** suggested DS would measure cm-depth surface currents [**now**: surface to 1.6 m depth mean]

=> What is the wind (“Ekman”) drift at cm-depth scales?

- Keulegan (1951), van Dorn (1953),..., O’Brien (1985),...Zelenke et al. (2012),.....:

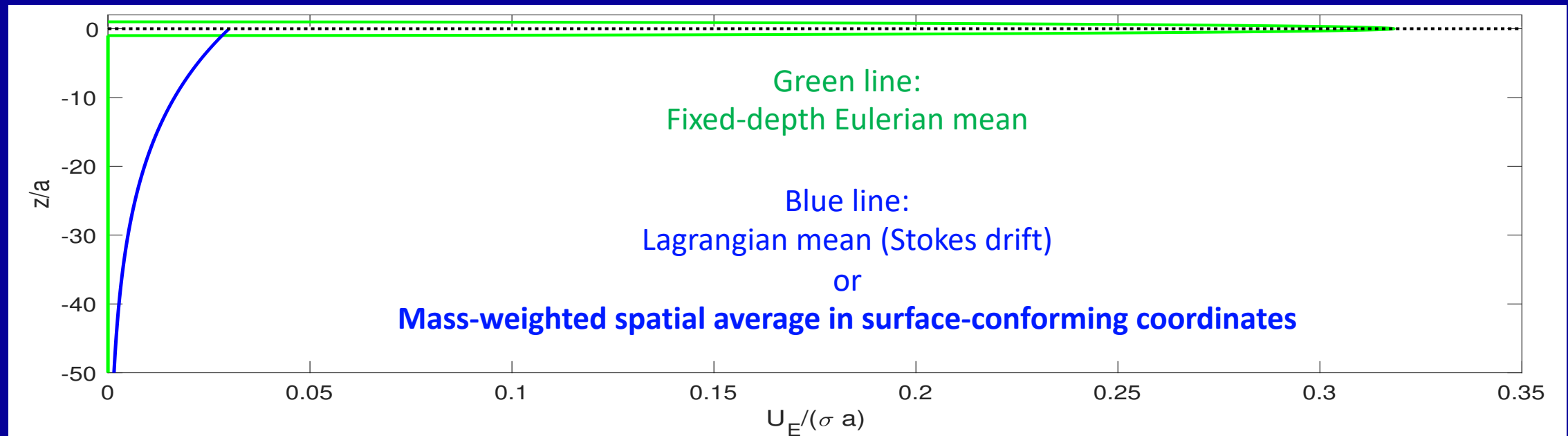
Surface wind drift is 3% of (10-m) wind speed at 15° to the right (NH) of wind...but why?

Turbulent universality theory gives first-order explanation (Samelson 2020) but neglects wave effects that are surely not negligible on ocean side of interface.

What about waves and wave drift?

What about waves and wave (Stokes) drift?

- Wave momentum (Stokes drift) of equilibrium-sea wave field is part of wind (“Ekman”) drift.
- Wave momentum is captured in full-depth Eulerian means:
 - Fixed-depth Eulerian mean places wave momentum above wave troughs.
 - Mass-weighted surface-conforming mean gives Eulerian mean profile equivalent to Stokes drift profile.



Equilibrium-sea wind (and wave) drift model:

- Wind drift model for the mass-weighted, surface-conforming mean current implicitly incorporates wave (Stokes) drift from the equilibrium wave field.
- Homogeneous, equilibrium balance: Coriolis force vs. stress divergence.
- How to model turbulent stress near the surface?
 - **Ocean roughness length** dependent on 10-m wind speed.
 - **Wave-effect parameter** dependent on 10-m wind speed, which – by analogy to Monin-Obukhov similarity theory – effectively modifies the classical wall-boundary value of the von Kármán constant.

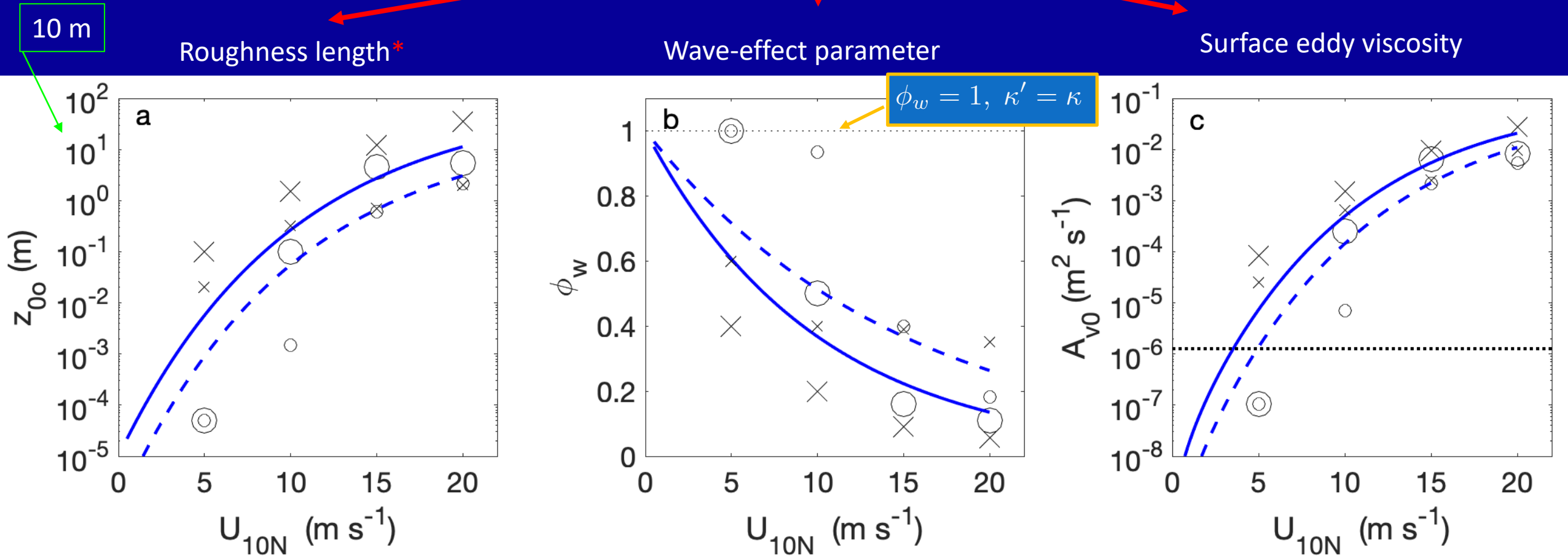
$$\tau = -\rho_o A_v \frac{dU}{dz}, \quad A_v(z; U_{10N}) = \phi_w(U_{10N}) \kappa u_* [z_{0o}(U_{10N}) - z]$$

(at z=0)

Roughness length*

Wave-effect parameter

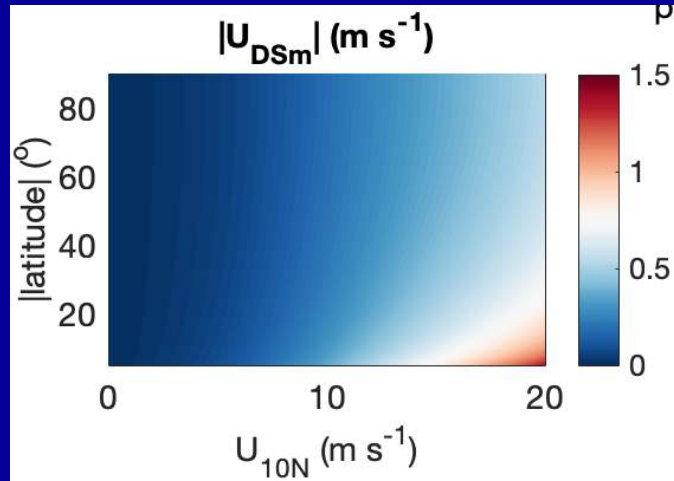
Surface eddy viscosity



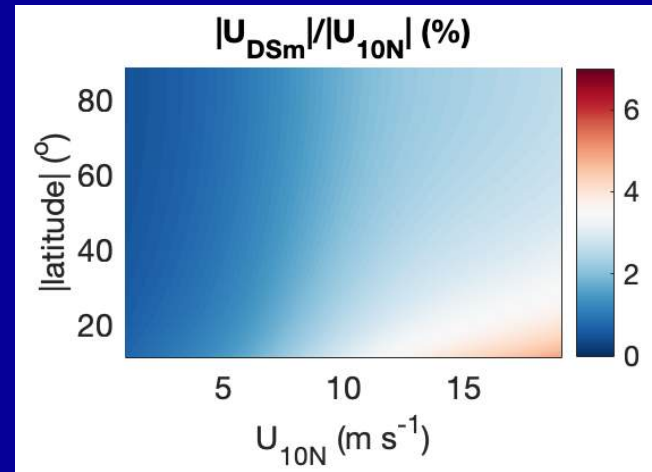
*Roughness length can be interpreted in terms of wave-breaking turbulence.

Model wind drift vs. 10-m wind speed and latitude

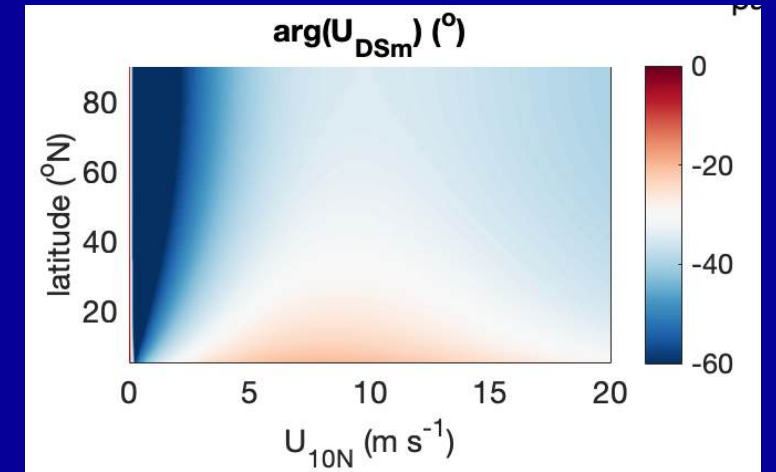
Drift speed



Fraction of 10-m wind speed

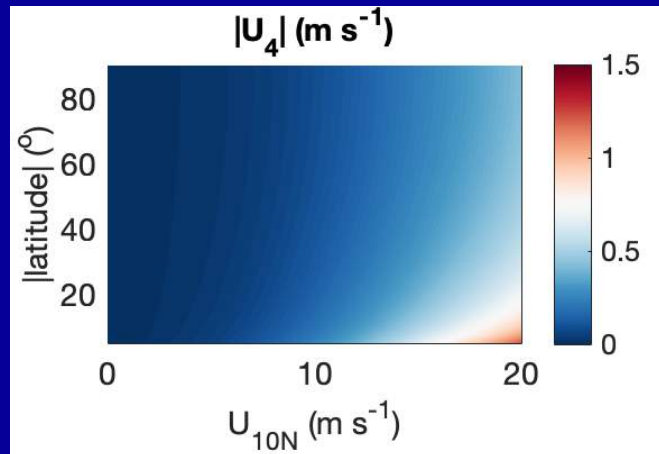


Wind-relative angle (NH)

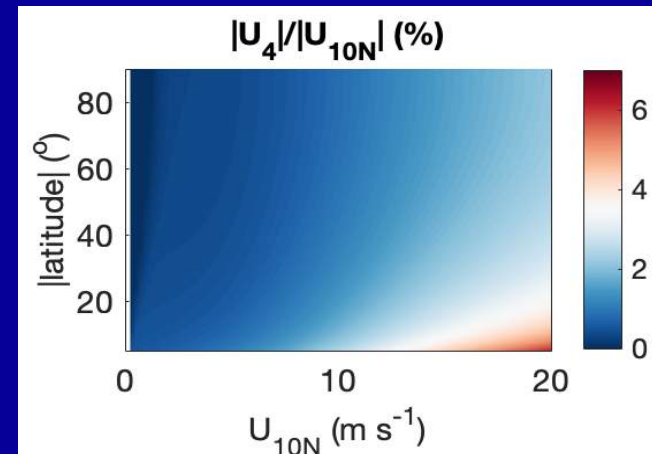


“DopplerScatt
mean”
0-1.6 m depth

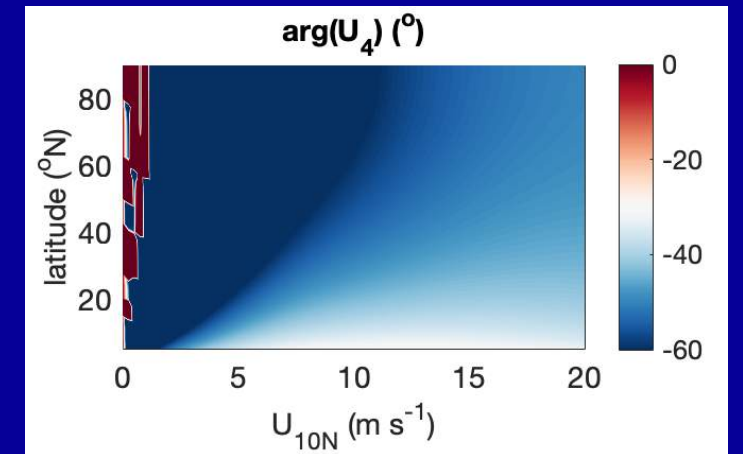
$|U_4|$ (m s⁻¹)



$|U_4|/|U_{10N}|$ (%)



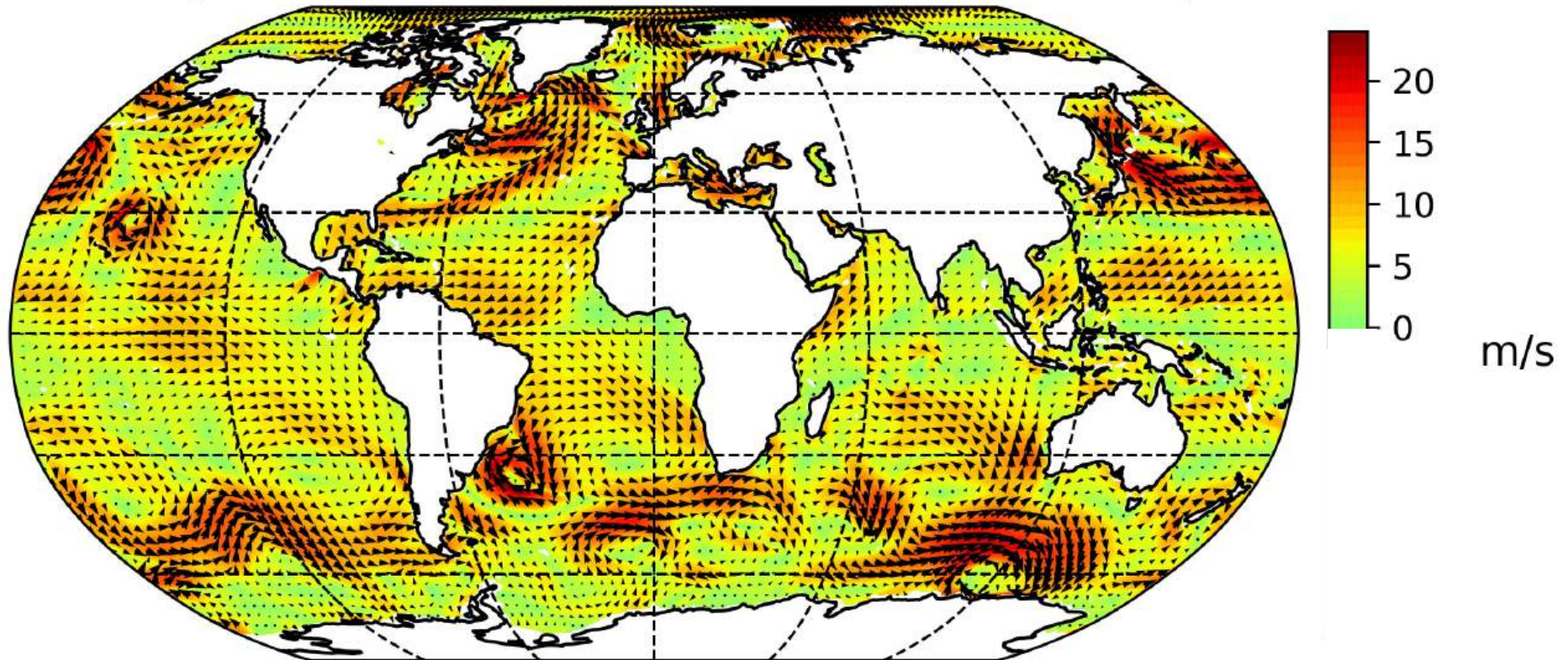
$\arg(U_4)$ (°)



4-m depth
[nominal
DopplerScatt
calibration
depth]

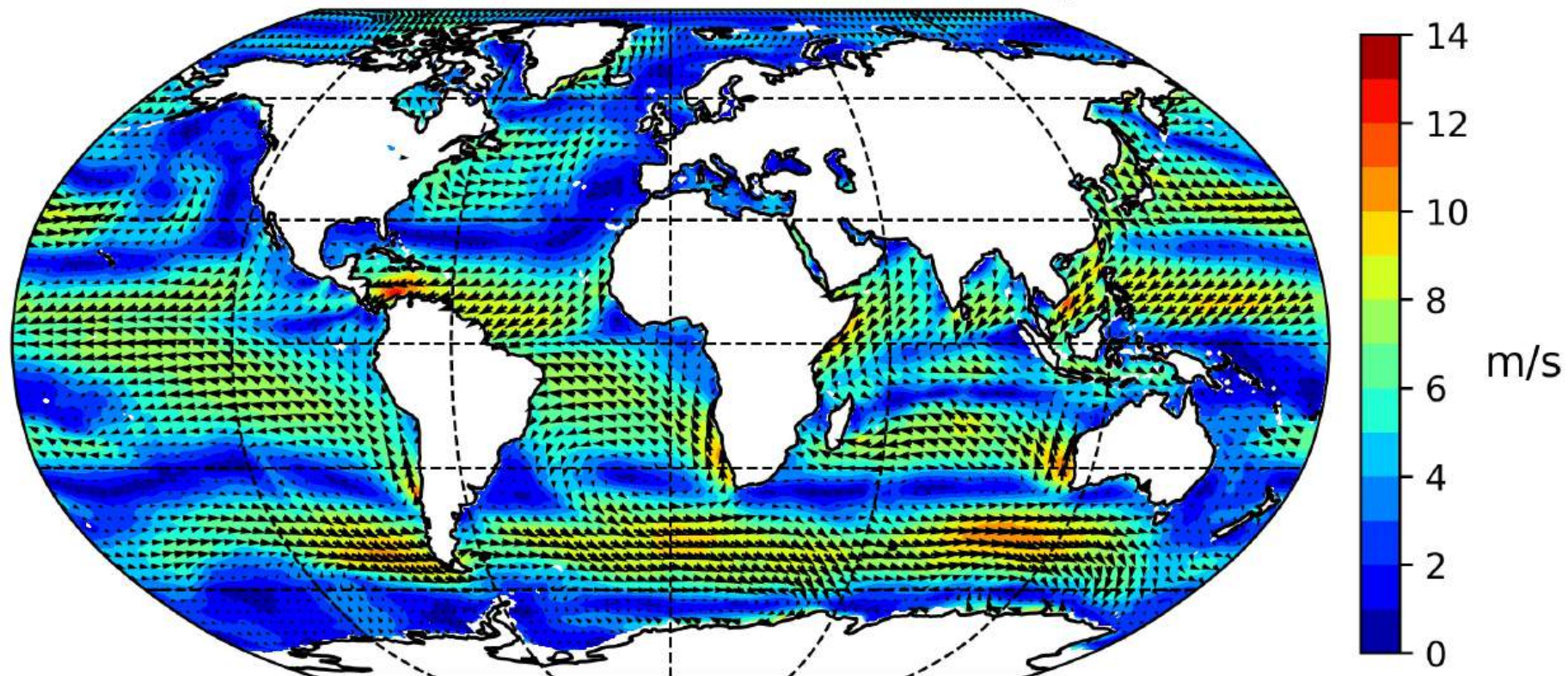
MERRA-2 winds: 01 Jan 1980 vector-mean of hourly fields

MERRA-2 Speed of vector-mean 10-m Wind, UTC 01Jan1980



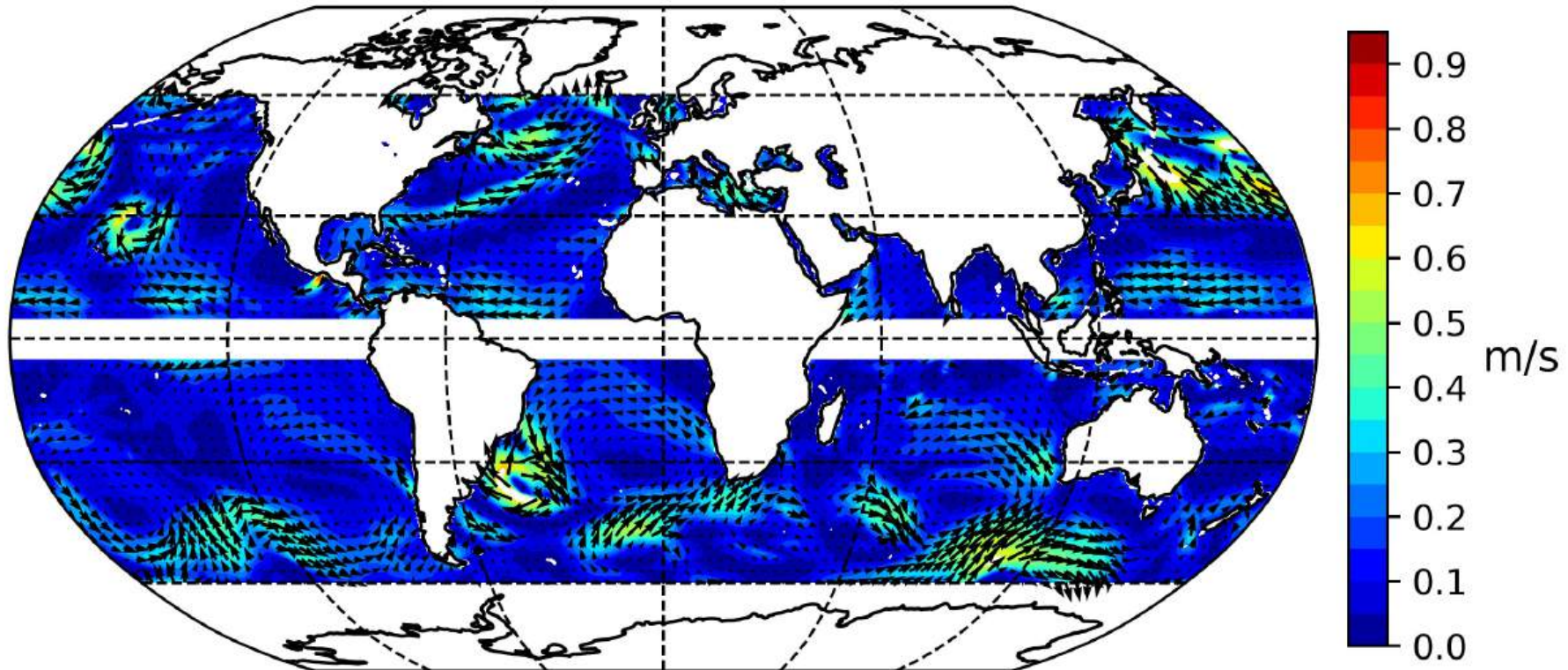
MERRA-2 winds: Jan 1980 monthly vector-mean

MERRA-2 Vector-mean 10-m Wind, UTC Jan1980



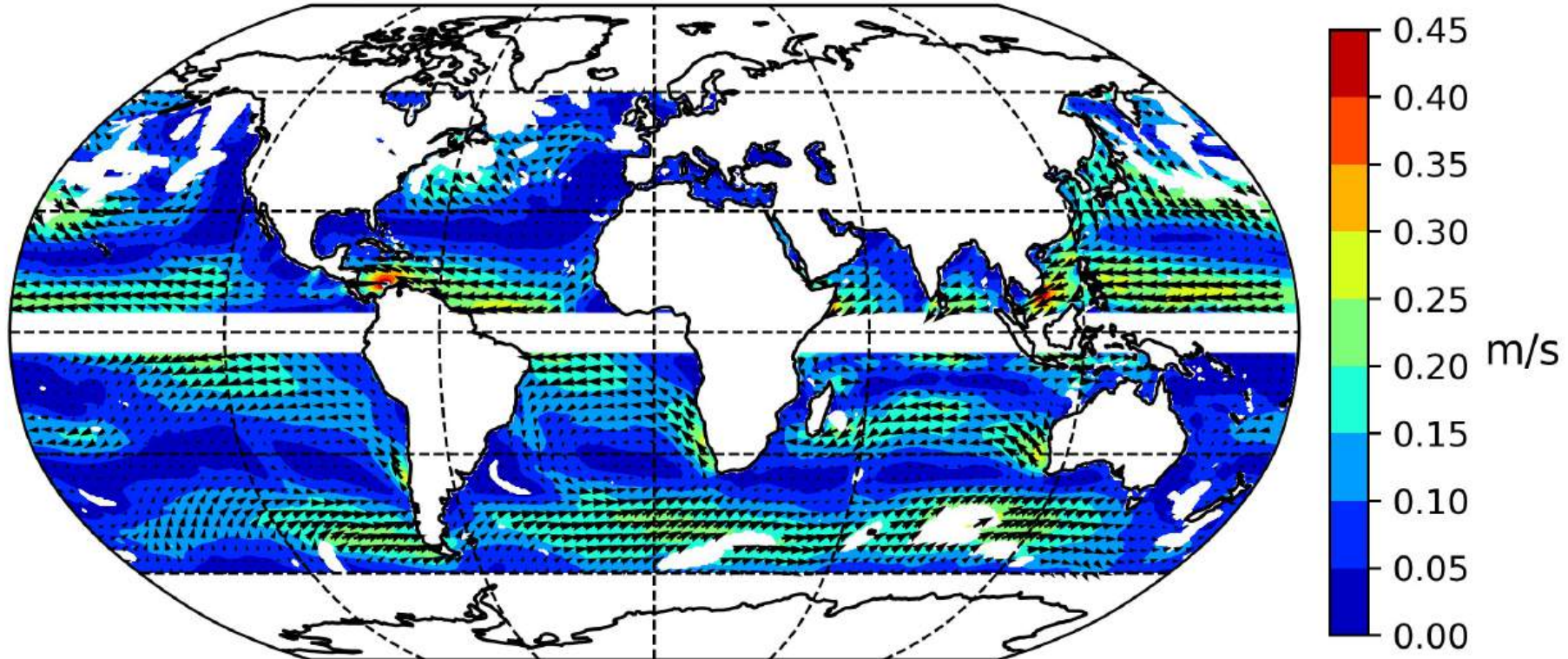
“DopplerScatt mean” wind drift: 01 Jan 1980 vector-mean

MERRA-2 |vec mean| 10-m DSp1 Surface wind drift, UTC 01Jan1980



“DopplerScatt mean” wind drift: Jan 1980 vector-mean

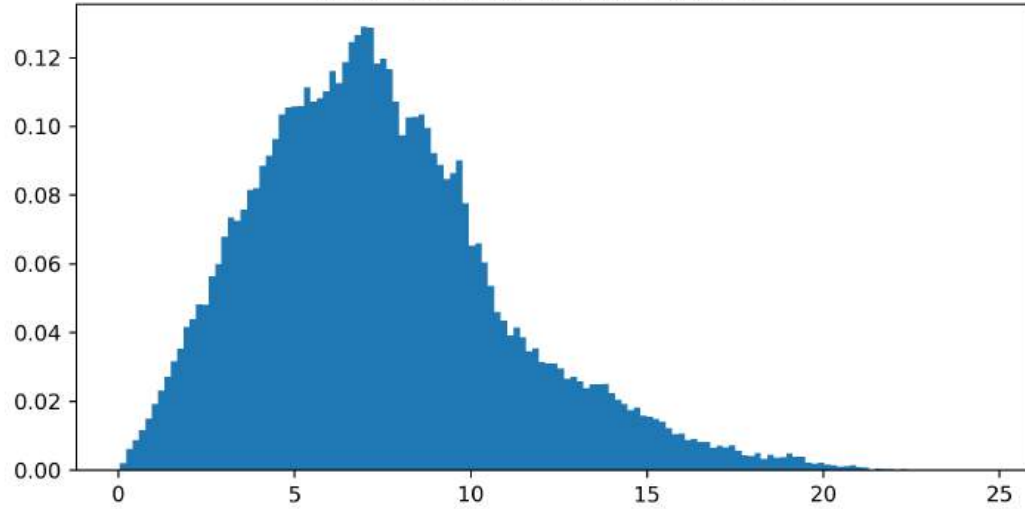
MERRA-2 |vec mean| 10-m DSp1 Surface wind drift, UTC Jan1980



Wind and drift pdfs – 01 Jan 1980

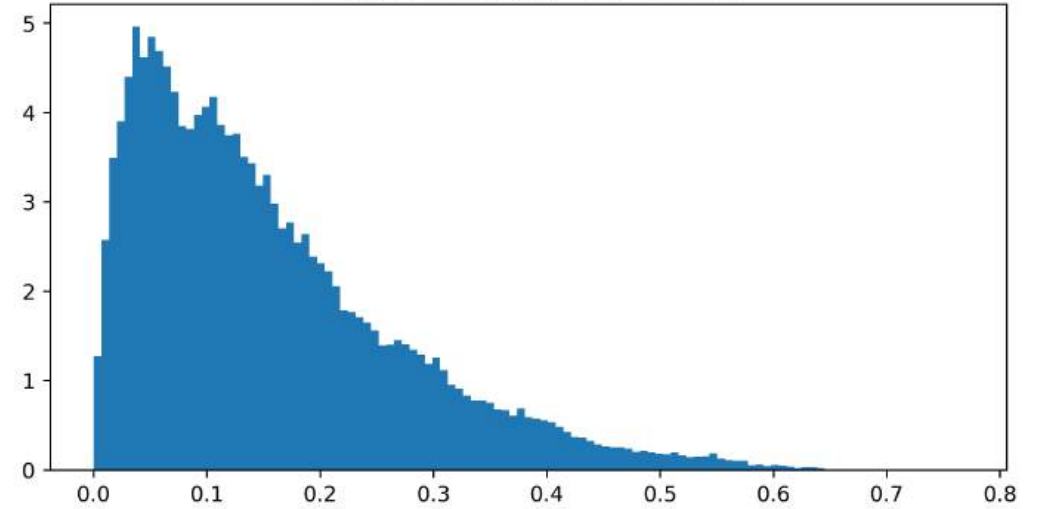
“DopplerScatt mean”

PDF(WS10Mm [m/s]) 01Jan1980



10 m s⁻¹

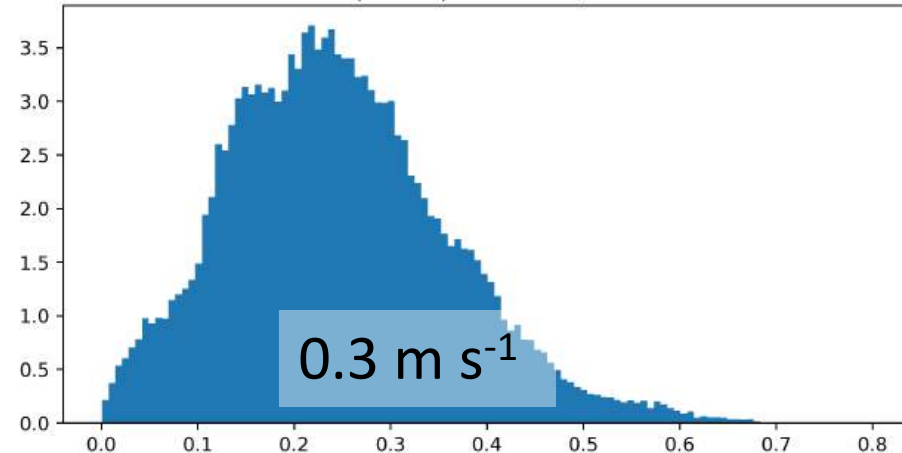
PDF(|U0m| [m/s]) 01Jan1980



0.3 m s⁻¹

Drift at air-sea
interface

PDF(|U0sfc| [m/s]) 01Jan1980

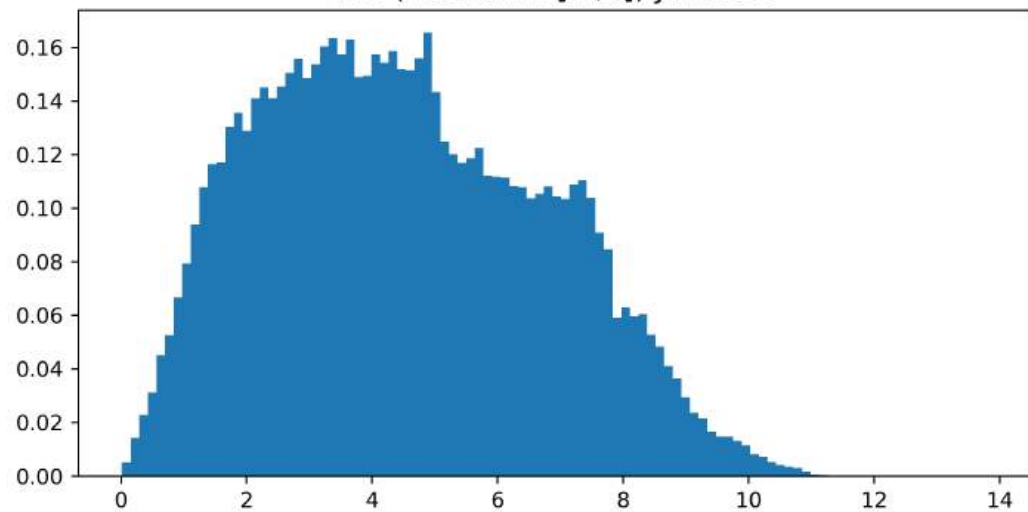


0.3 m s⁻¹

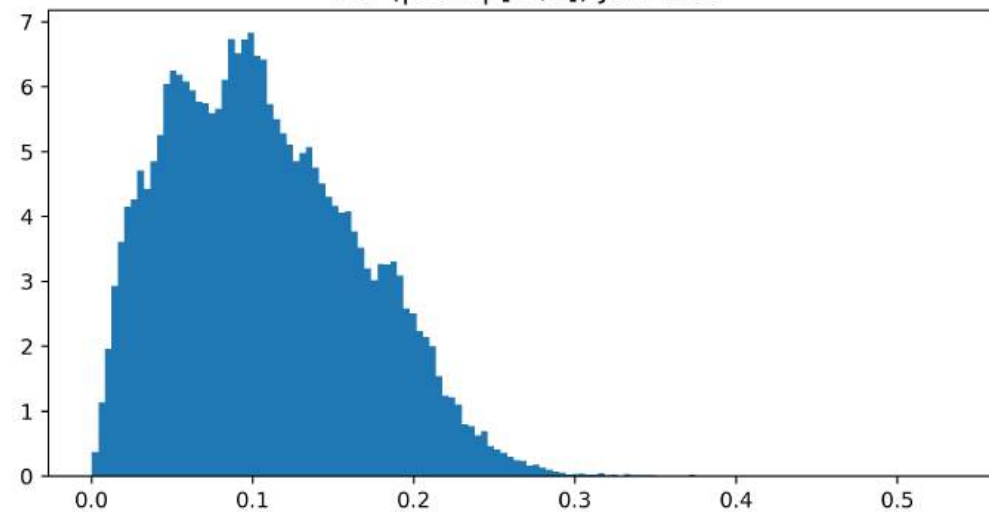
Wind and drift pdfs – Jan 1980

“DopplerScatt mean”

PDF(WS10Mm [m/s]) Jan1980



PDF(|U0m| [m/s]) Jan1980

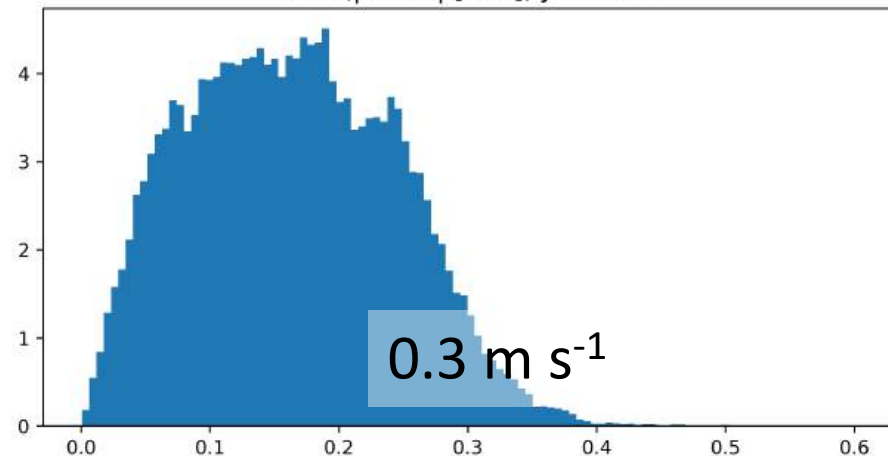


10 m s⁻¹

0.3 m s⁻¹

Drift at air-sea interface

PDF(|U0sfc| [m/s]) Jan1980



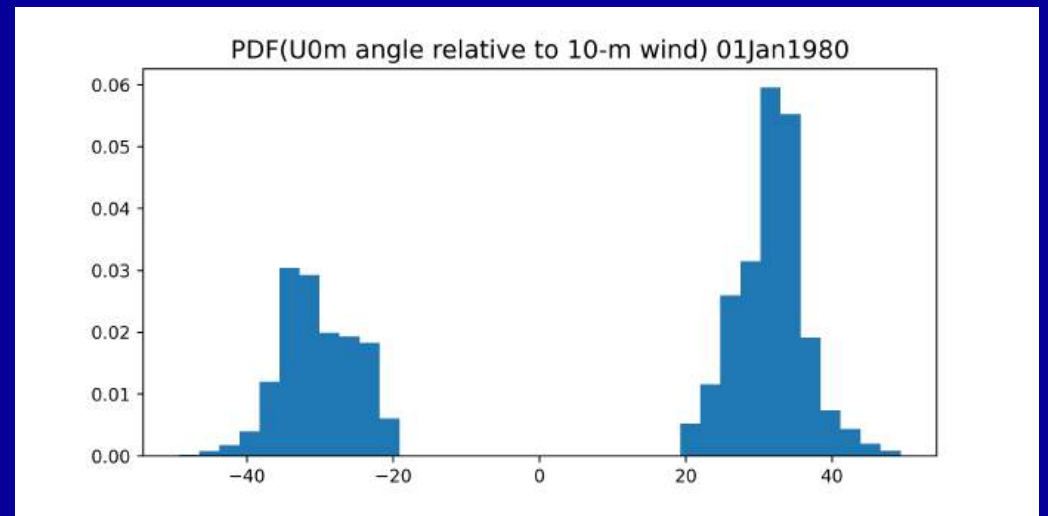
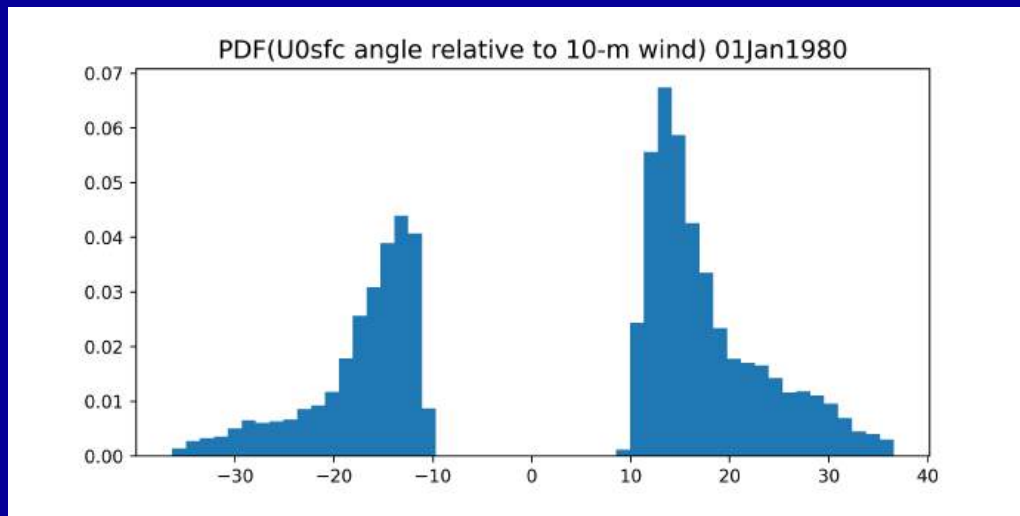
0.3 m s⁻¹

Relative drift-angle pdfs

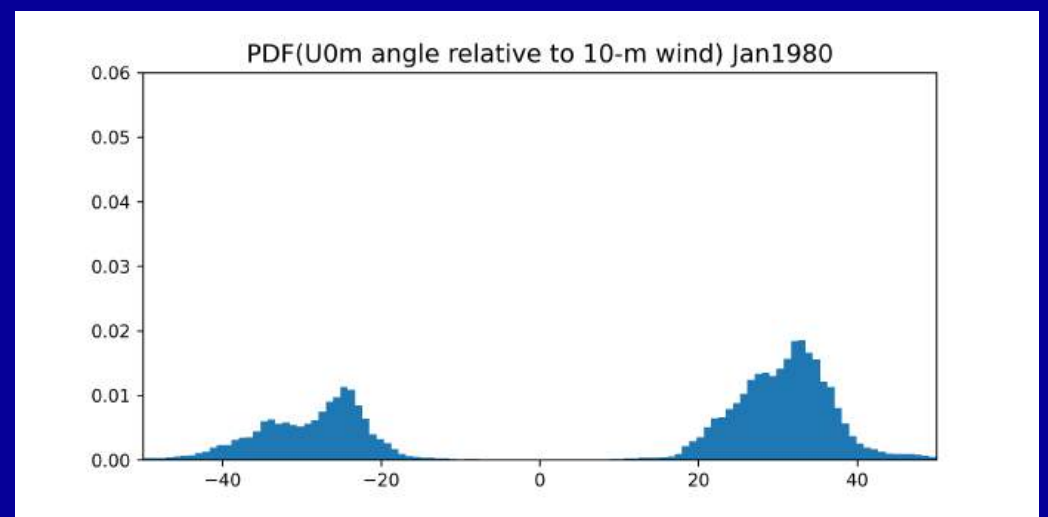
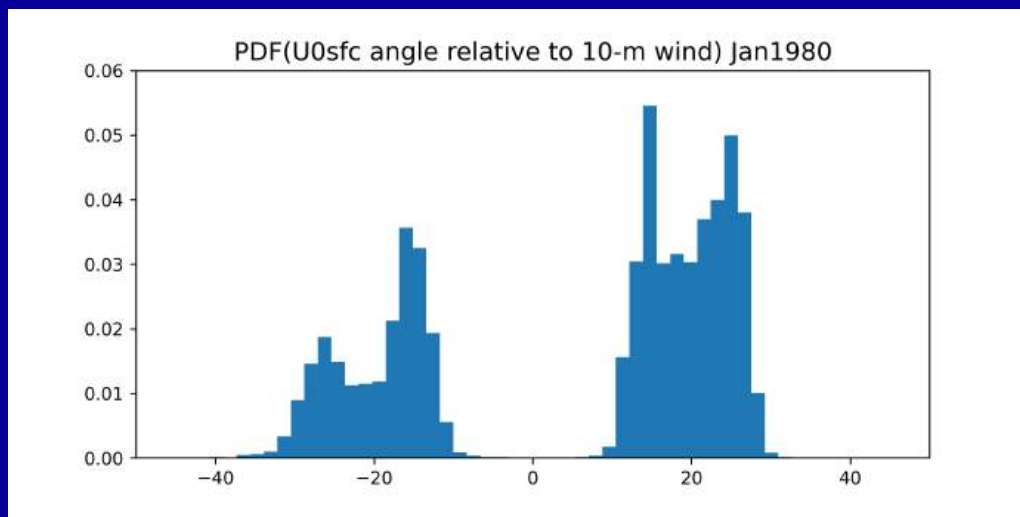
Air-sea interface drift

“DopplerScatt mean”

01 Jan 1980



Jan 1980



Summary

- Analysis in progress of global statistics of near-surface wind and wave drift from recently proposed equilibrium-sea model (MERRA-2 reanalysis winds; ODYSEA risk reduction).
- Typical values of “DopplerScatt” 1-day mean drift are $0.1\text{-}0.2\text{ m s}^{-1}$ and can exceed 0.5 m s^{-1} .
- Typical values of “DopplerScatt” monthly mean drift are $0.05\text{-}0.15\text{ m s}^{-1}$ and can exceed 0.25 m s^{-1} .
- Transient mid-latitude winds give relatively large vector-mean drift at mid-latitudes on daily timescales.
- Quasi-steady low-latitude winds give relatively large vector-mean drift at low latitudes on monthly time scales.

Drift curl and divergence pdfs

