Air-sea interaction in DYNAMO and PISTON: MJO wind bursts, tropical cyclones, and monsoon tails

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with contributions from

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image from NASA GSFC

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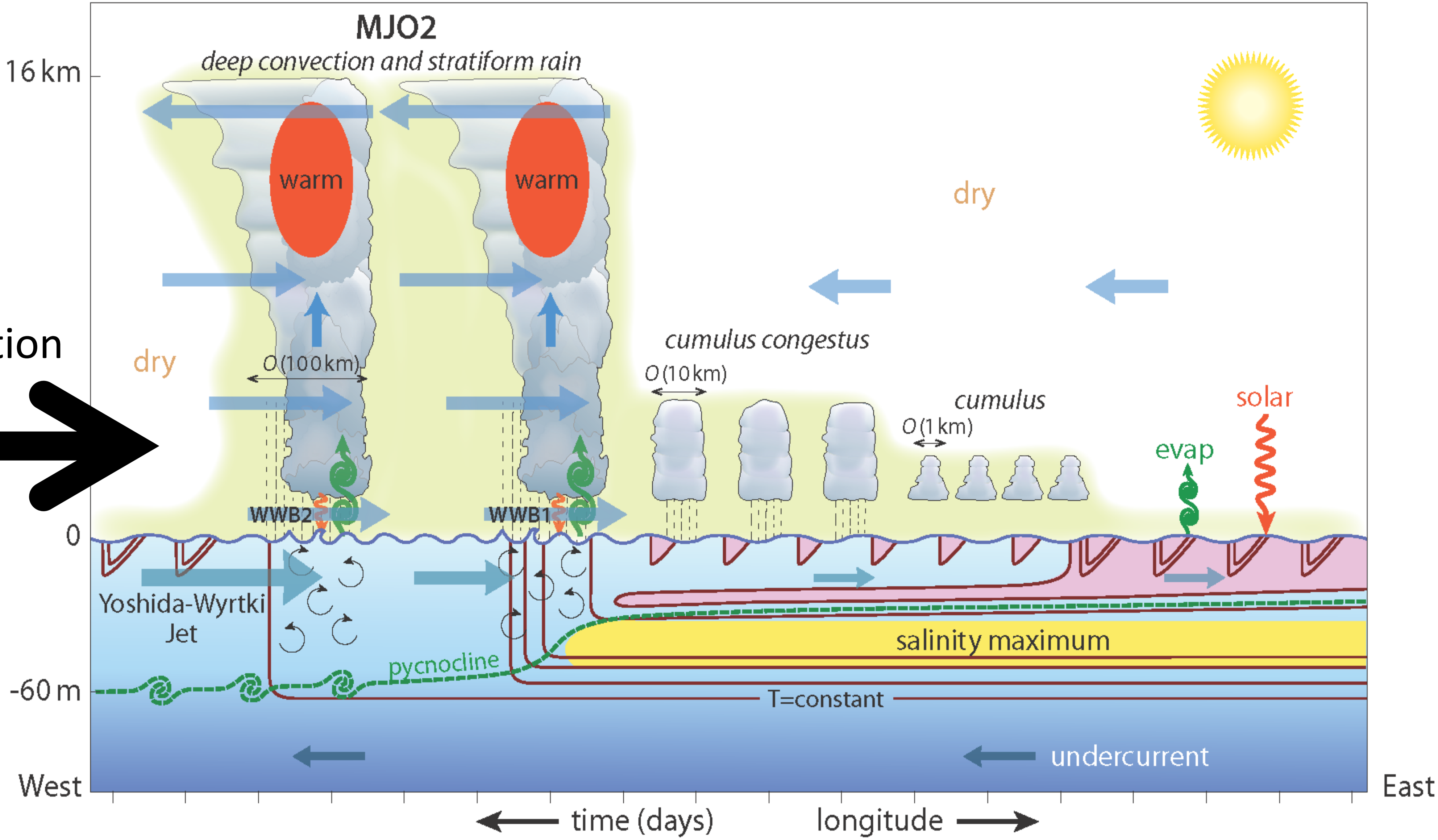
1. **Air-sea interaction phenomena**
   - intraseasonal variability, tropical cyclones, *monsoon tails*
   - wind bursts
   - diurnal warm layers in calm wind
   - cumulus clouds coupled to the subcloud atmospheric mixed layer
   - cold pools

2. **Observations**
   - surface fluxes: turbulent and radiative
   - atmospheric soundings
   - atmospheric turbulence in the surface mixed layer, stratiform rain, and clouds

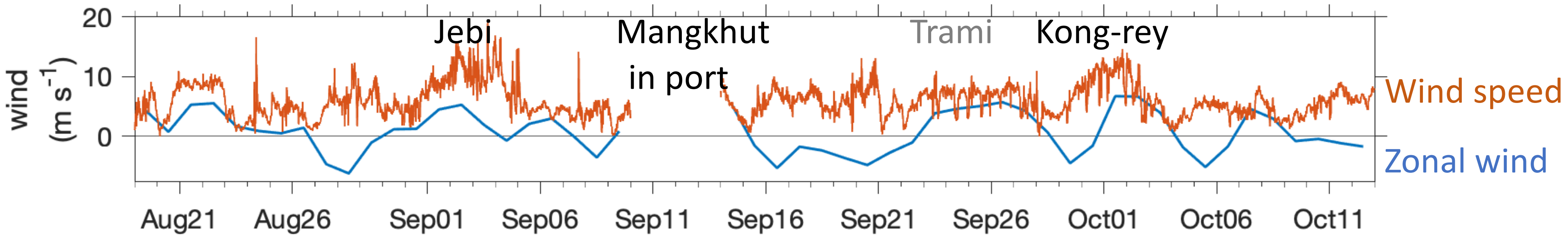
Air-sea interactions in the MJO from DYNAMO

propagation



Moum et al. 2014

PISTON wind speed and surface heat fluxes from R/V *Thompson*



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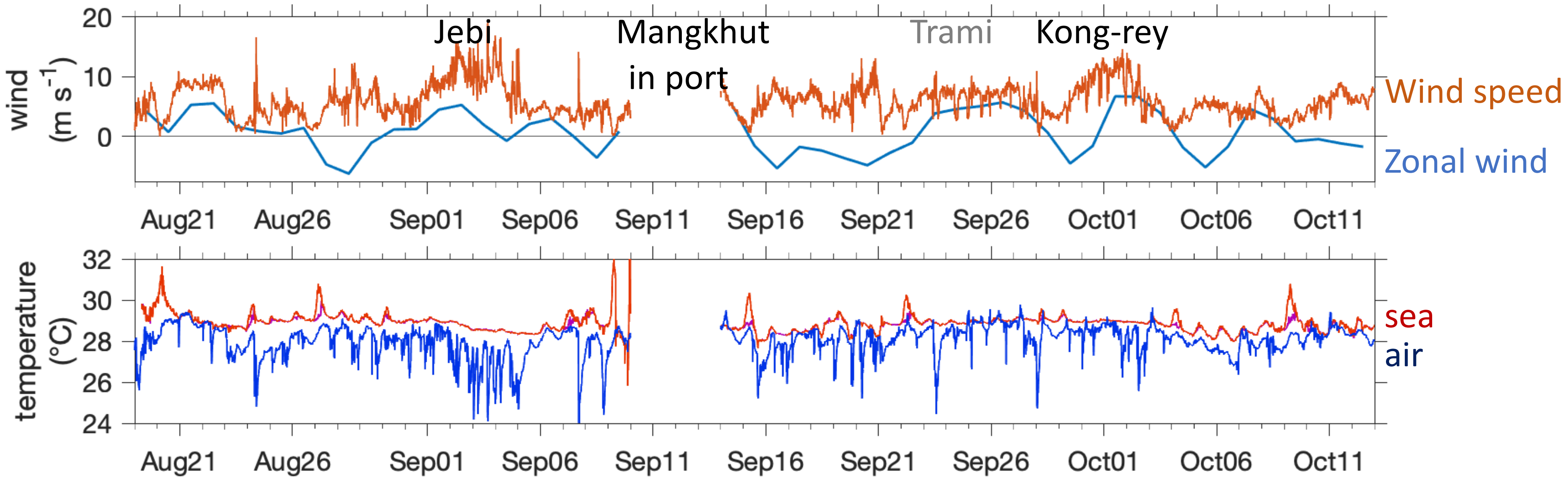

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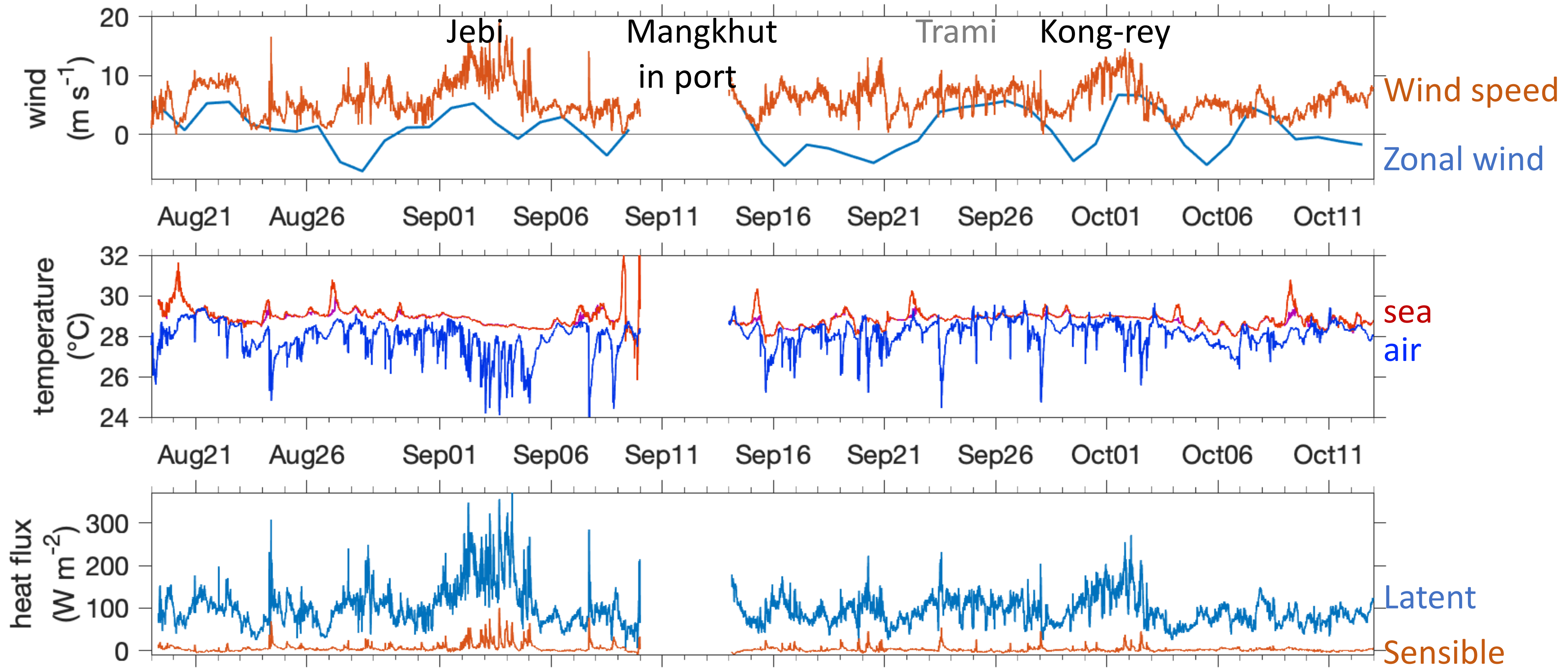
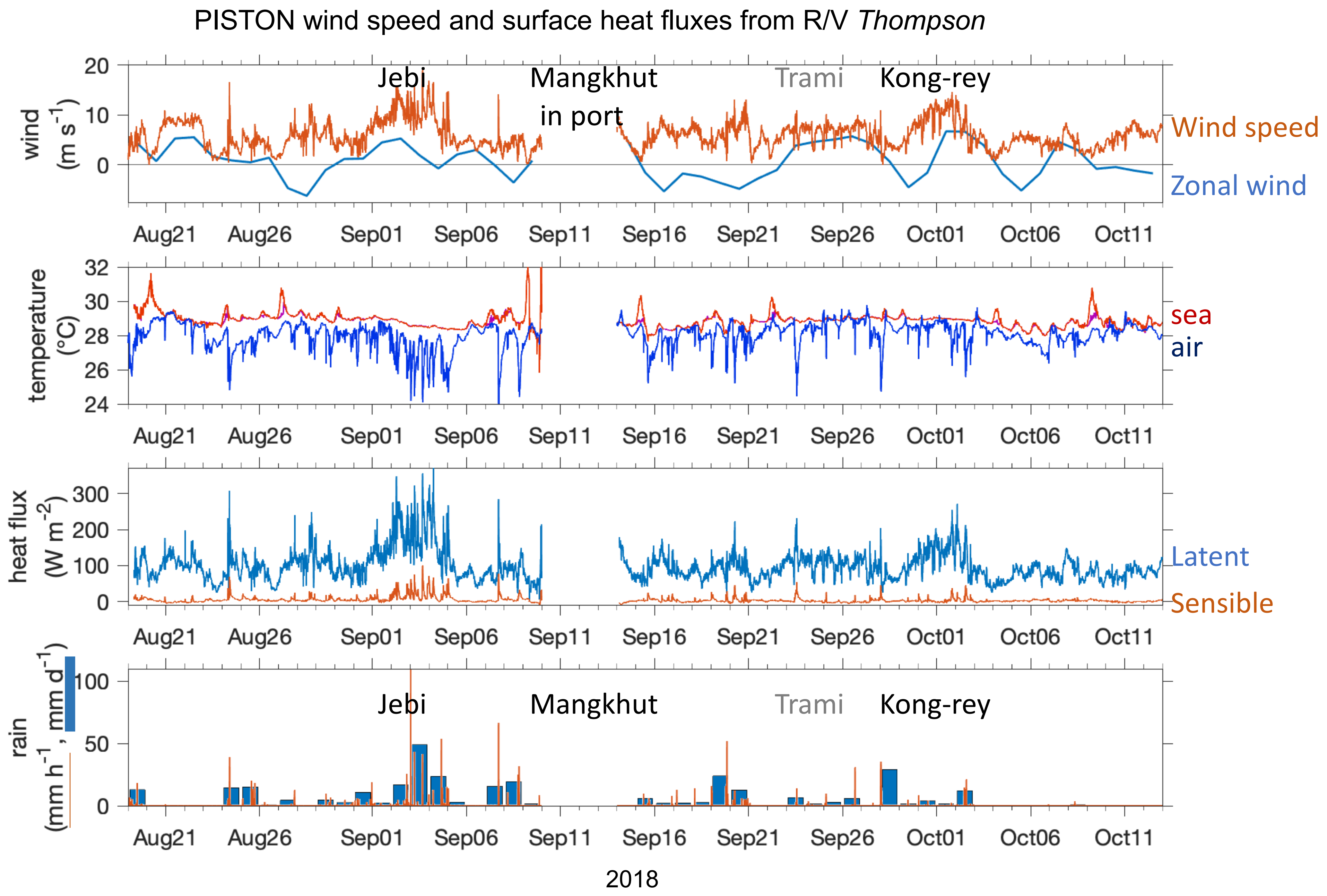
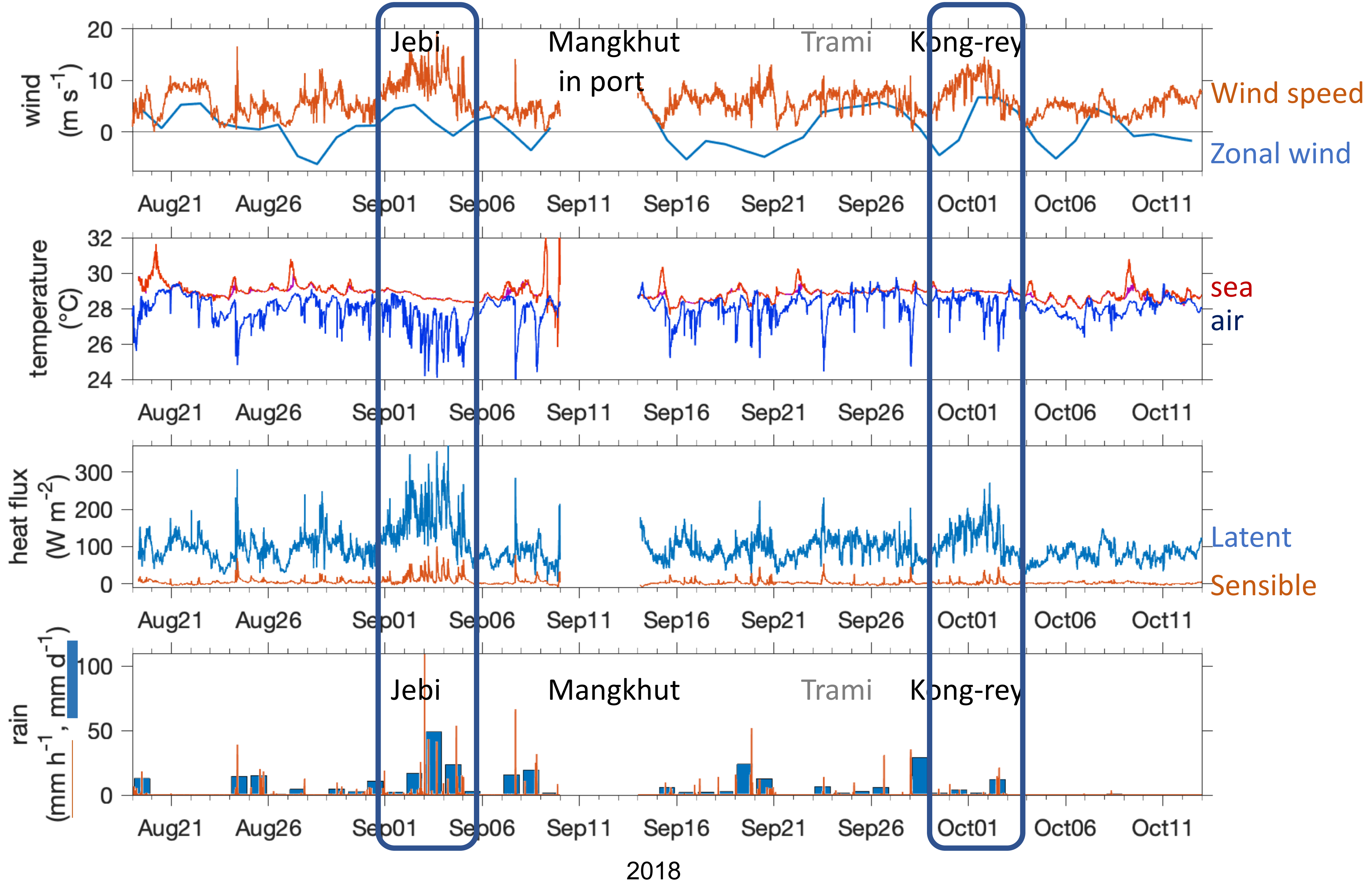
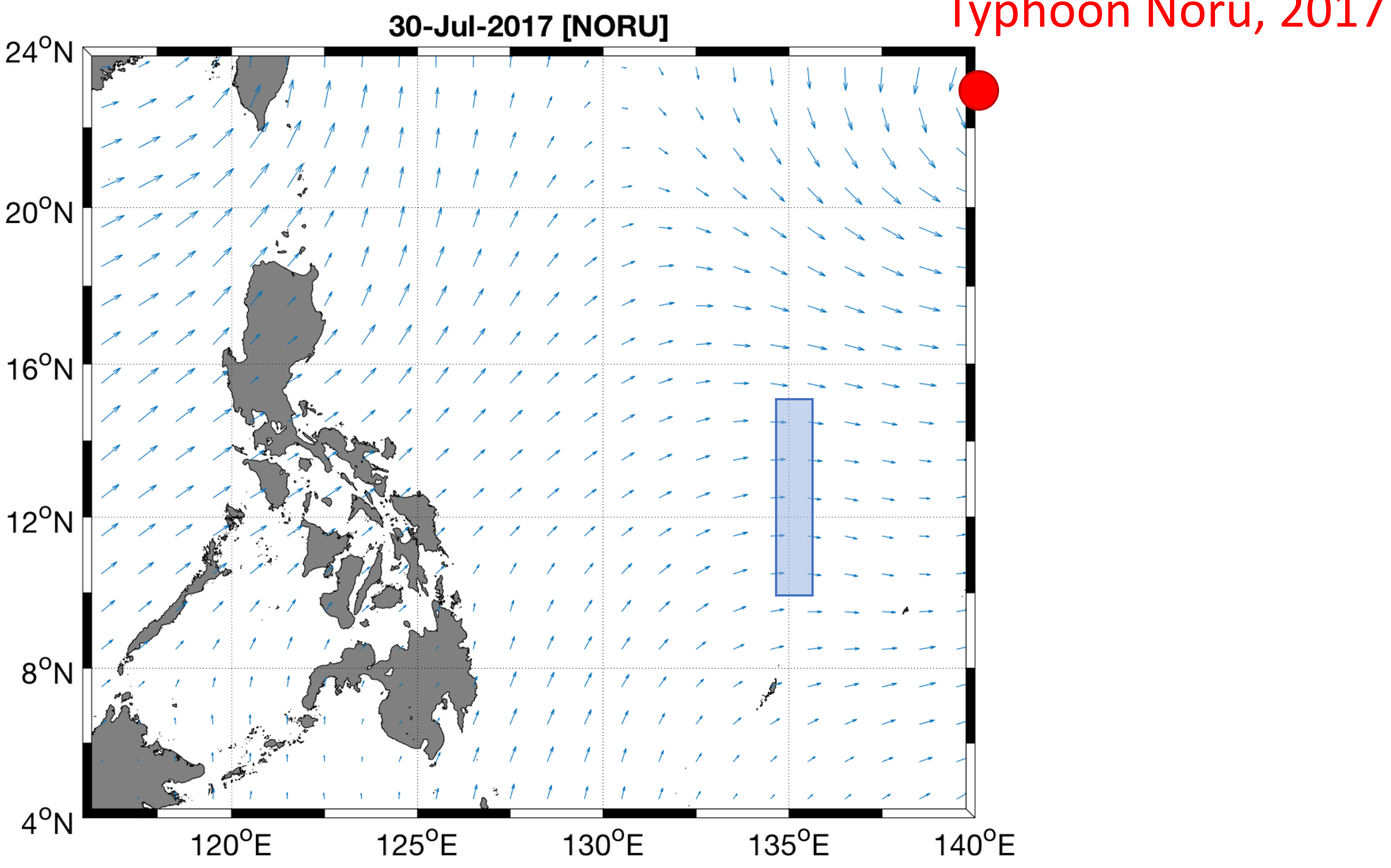



PISTON wind speed and surface heat fluxes from R/V Thompson
wind (m s-1)
Jebi
Mangkhut
in port
Trami
Kong-rey
Wind speed
Zonal wind
temperature (°C)
sea
air
heat flux (W m-2)
Latent
Sensible
rain (mm h-1, mm d-1)
Jebi
Mangkhut
Trami
Kong-rey
Aug21
Aug26
Sep01
Sep06
Sep11
Sep16
Sep21
Sep26
Oct01
Oct06
Oct11
2018

PISTON wind speed and surface heat fluxes from R/V *Thompson*



Western Pacific *monsoon tails*



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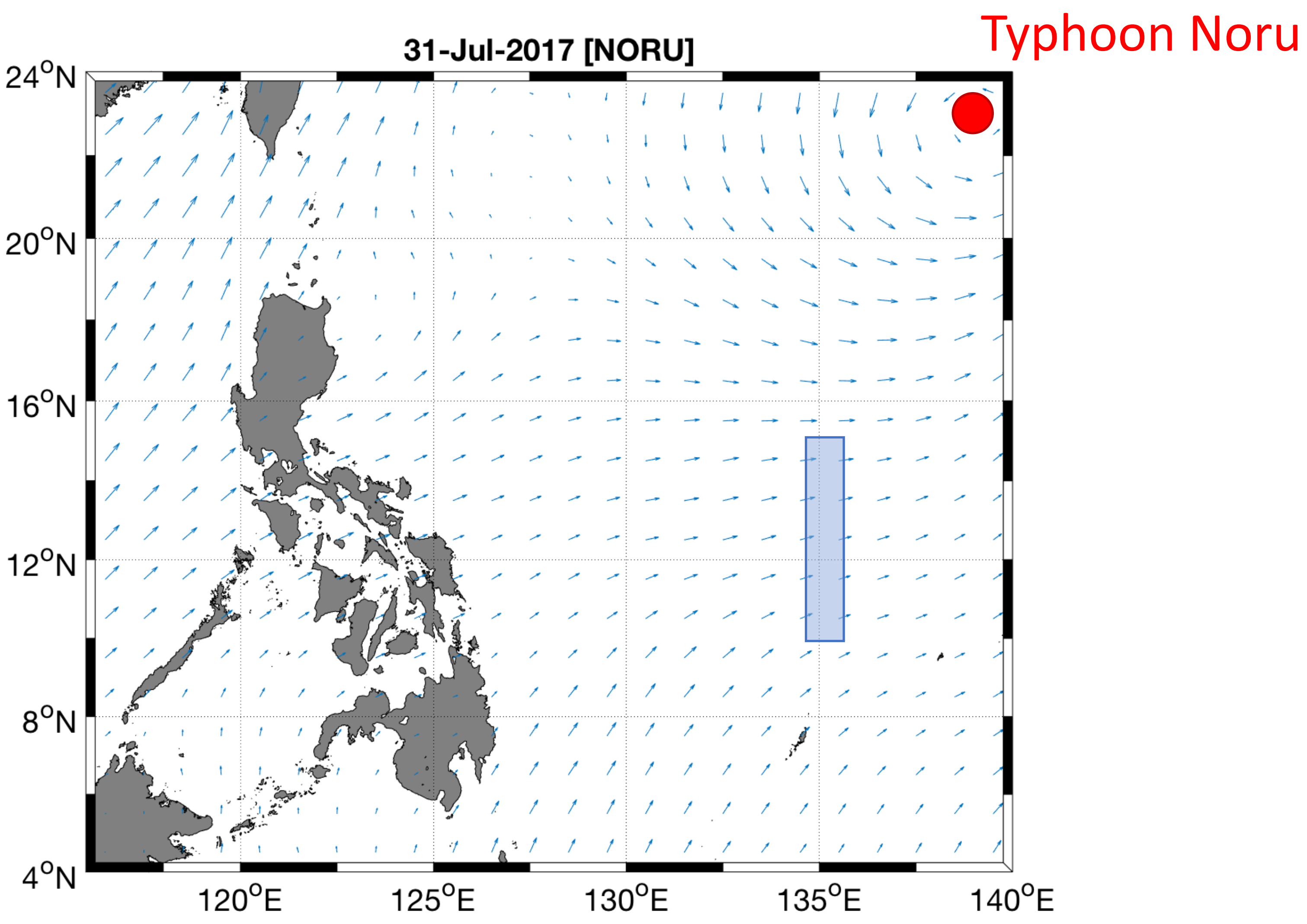

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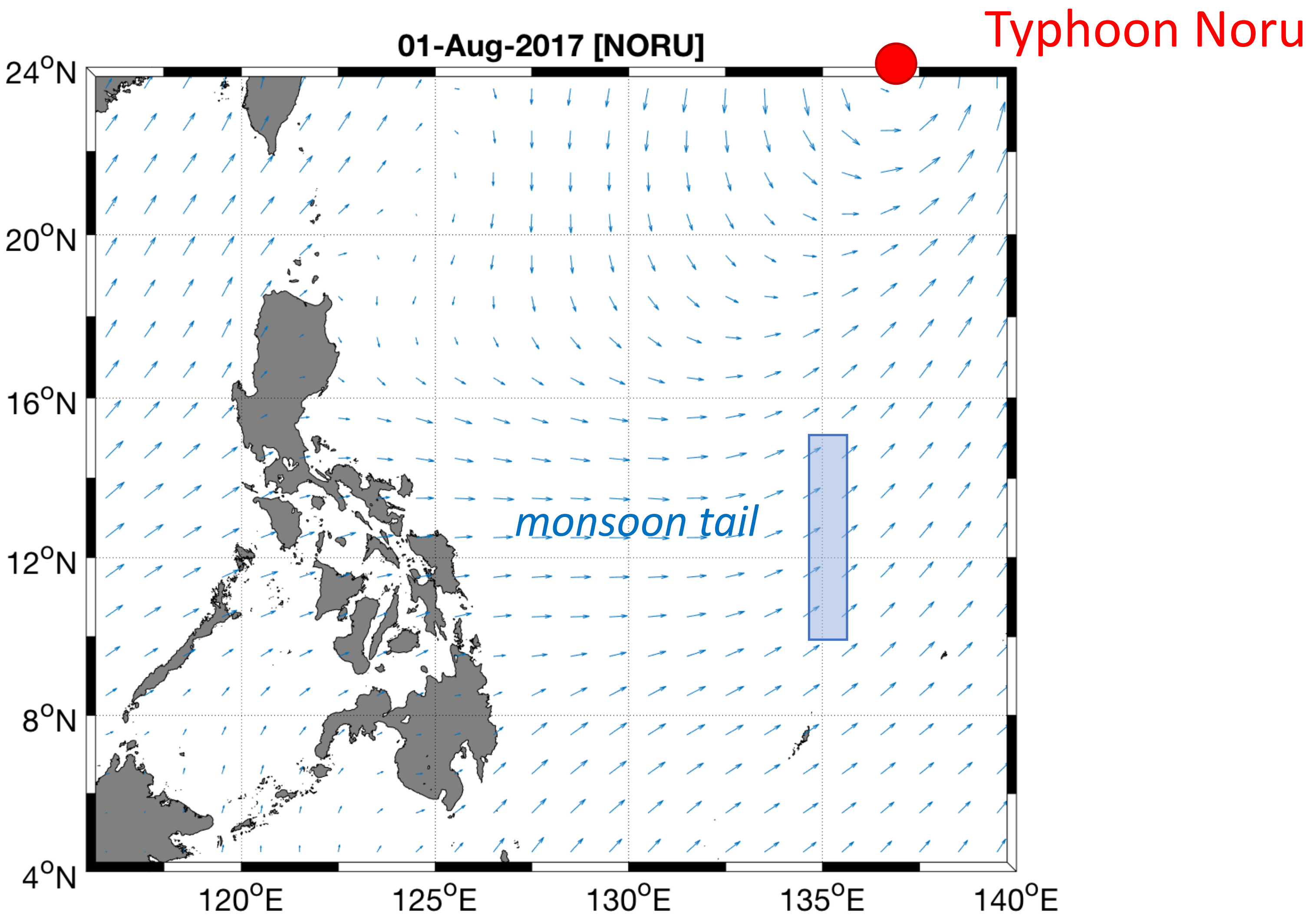
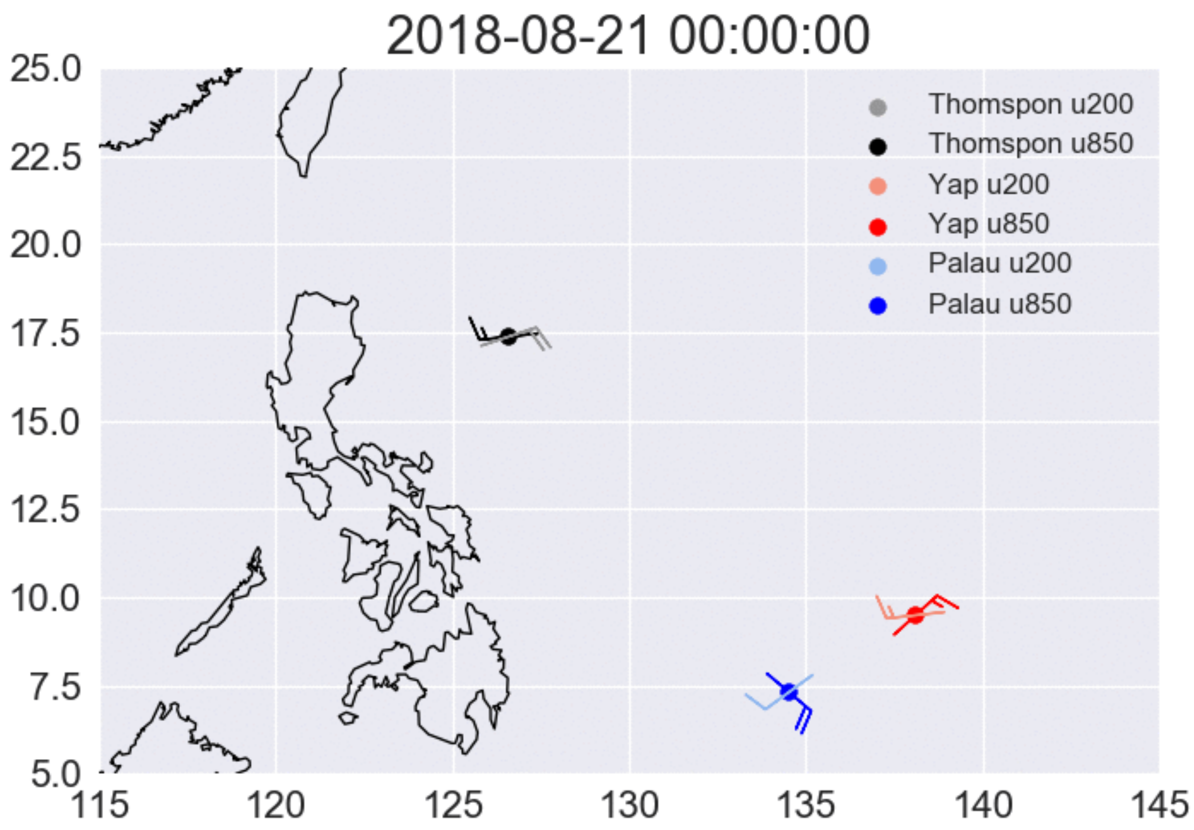


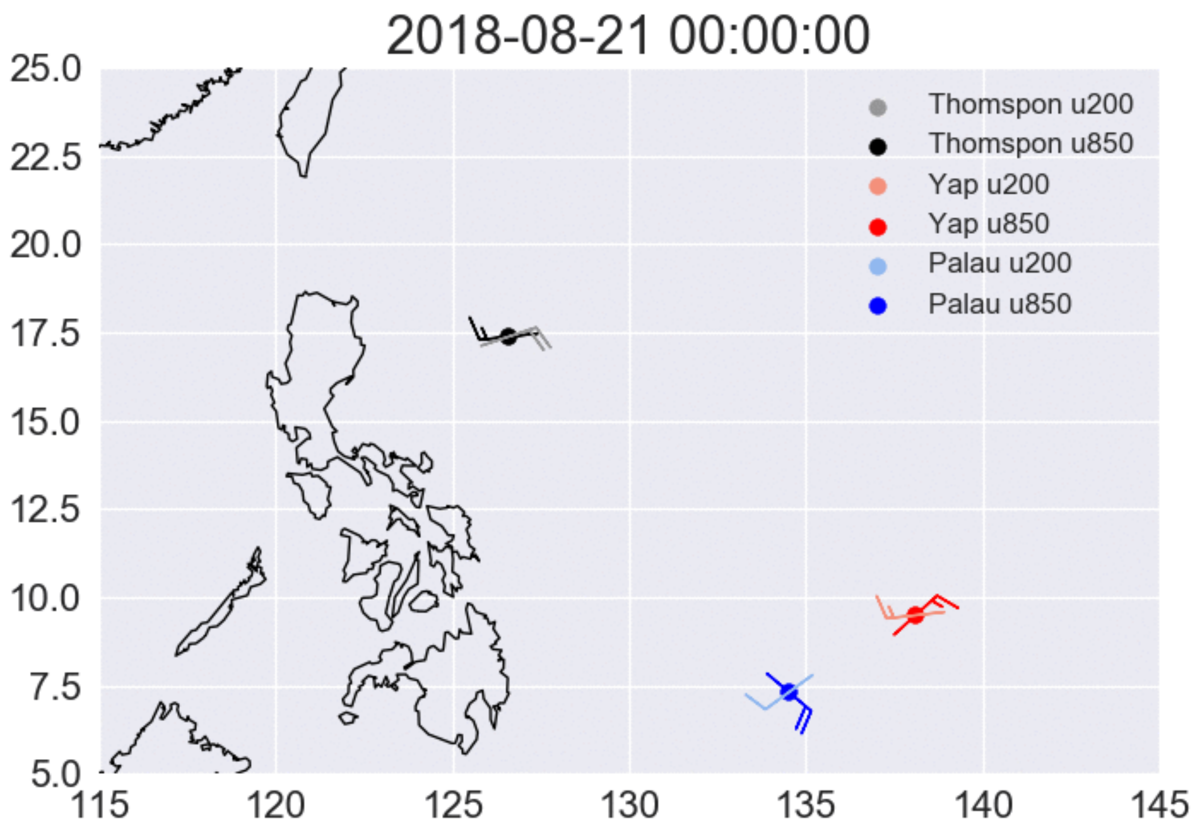
Propagation of Intraseasonal Tropical Oscillations (PISTON) sounding array of opportunity



Z. Martin and K. Chudler

Propagation of Intraseasonal Tropical Oscillations (PISTON) sounding array of opportunity

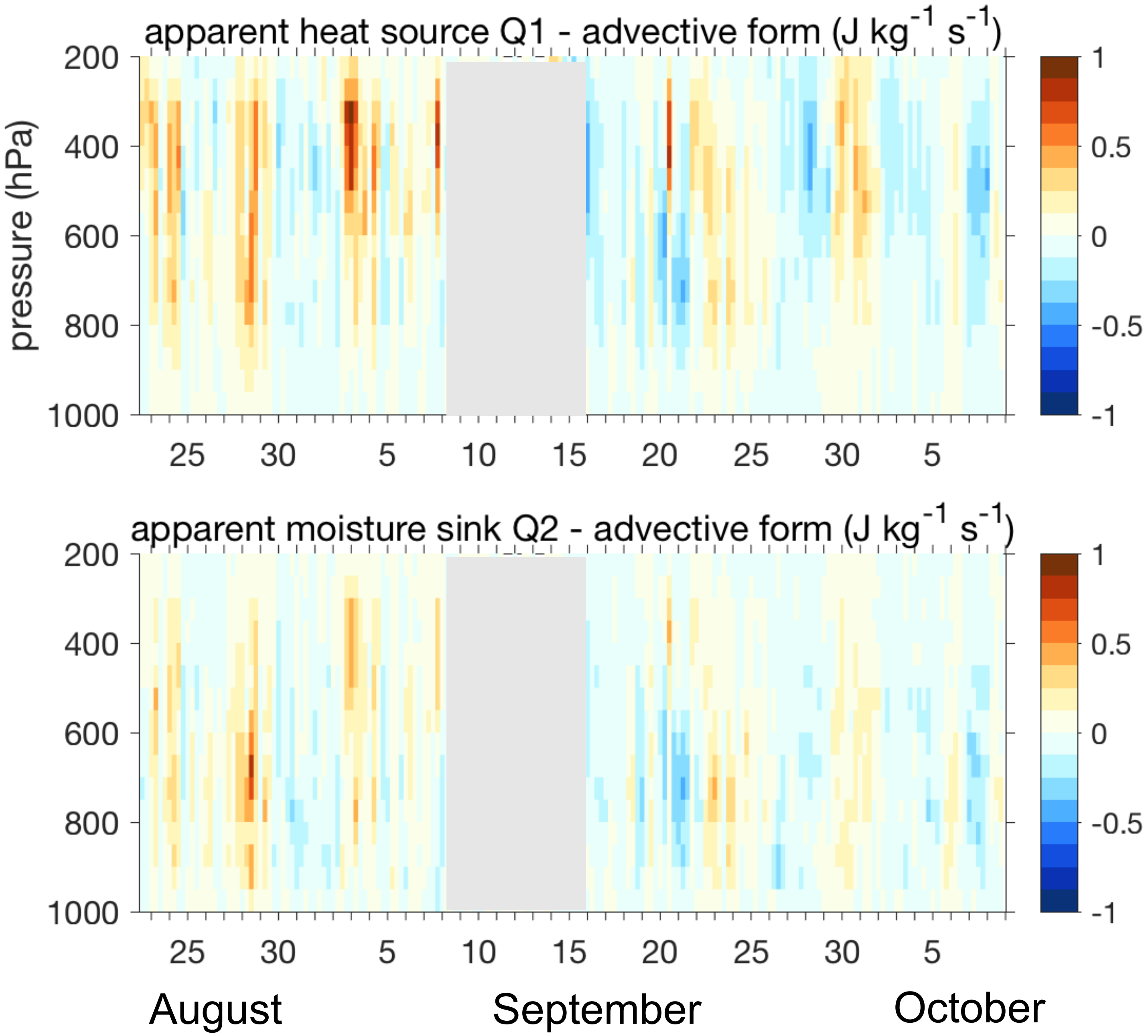
Compute gradients of
u, v, T, q, (s, h)
from the triangle of 3 sounding locations.



Z. Martin and K. Chudler

$$Q_1 \equiv \frac{\partial \bar{s}}{\partial t} + \overline{\nabla \cdot s\mathbf{V}} + \frac{\partial \bar{s}\bar{\omega}}{\partial p}$$

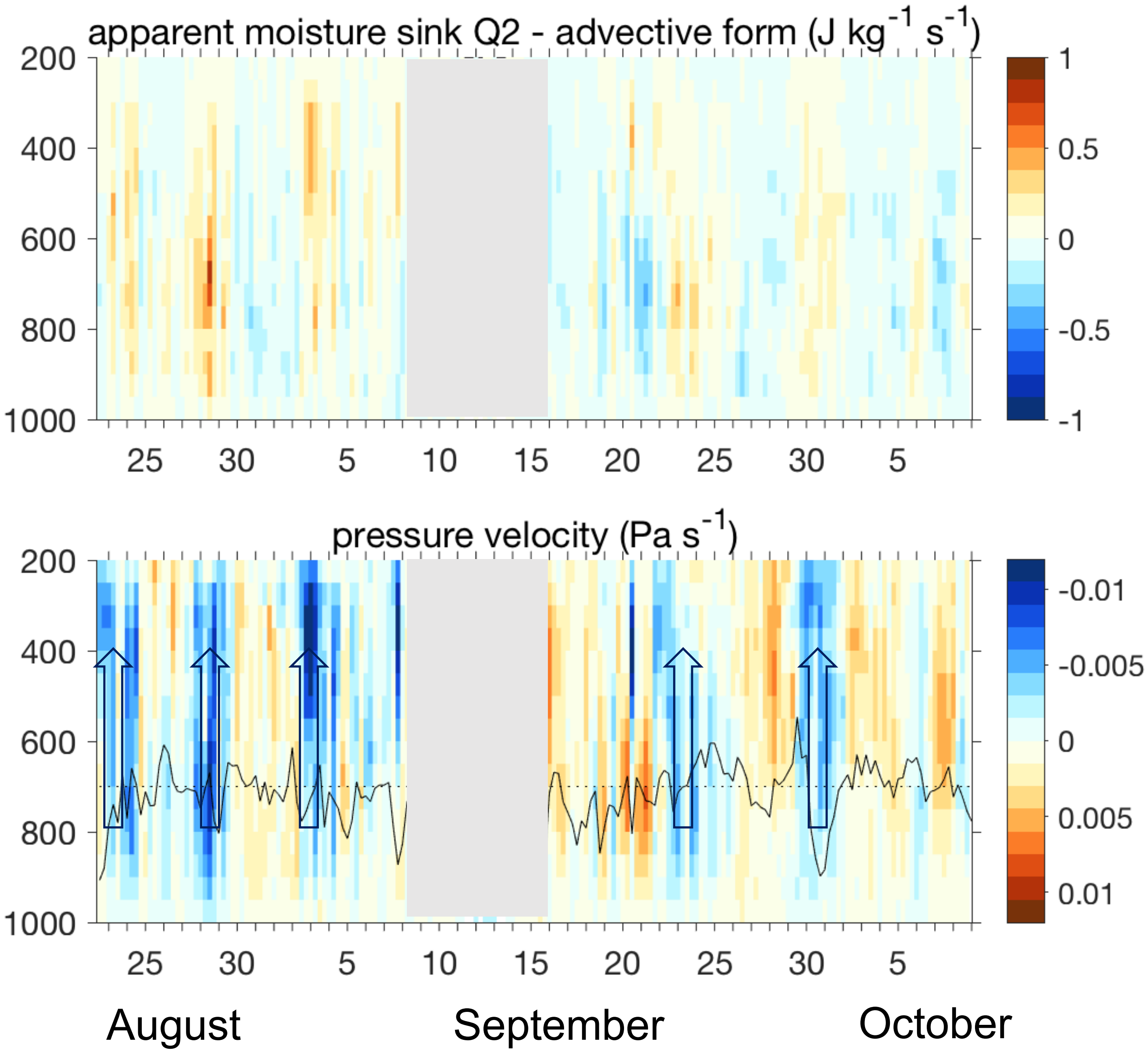
$$Q_2 \equiv -L\left(\frac{\partial \bar{q}}{\partial t} + \overline{\nabla \cdot q\mathbf{V}} + \frac{\partial \bar{q}\bar{\omega}}{\partial p}\right)$$



Yanai, Esbensen, and Chu (1973)

Moist static energy (MSE)
$h = c_p T + gz + Lq$
variations depend mostly on moisture.

moisture convergence
≈ vertical transport



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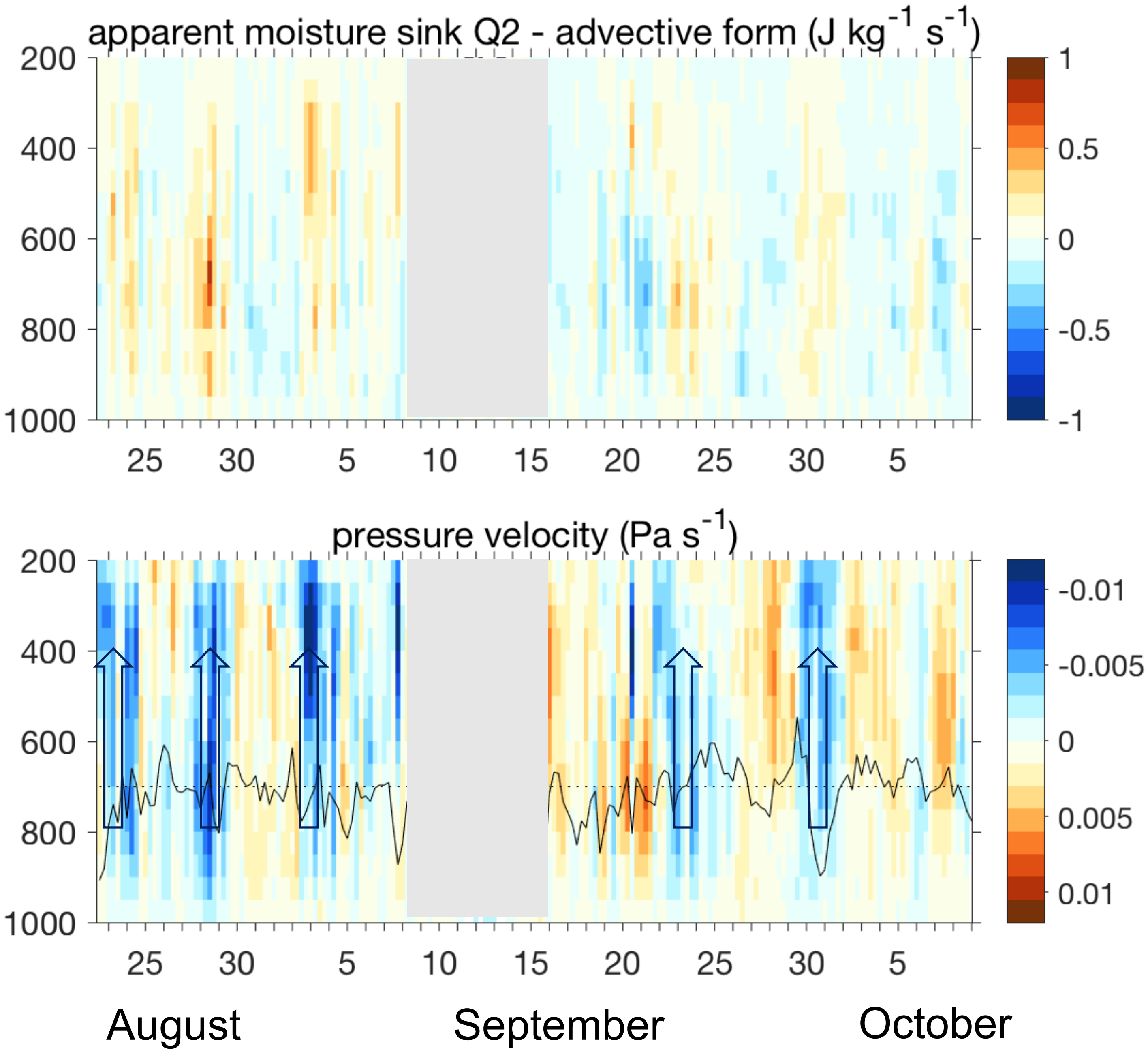
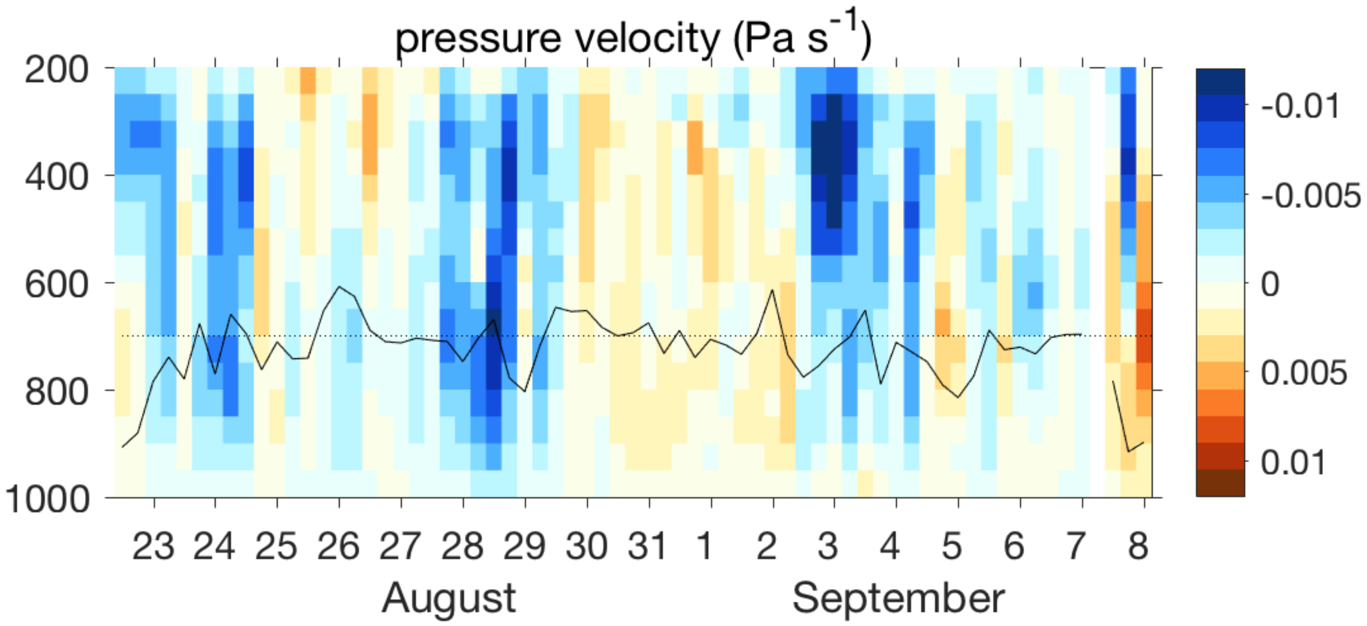
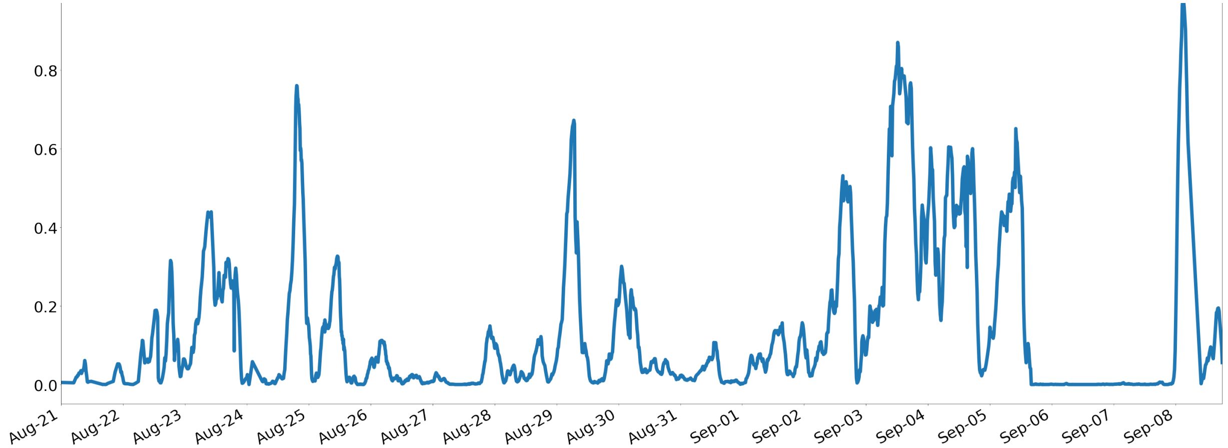
≈ vertical transport
≈ precipitation



Large-scale vertical (pressure) velocity



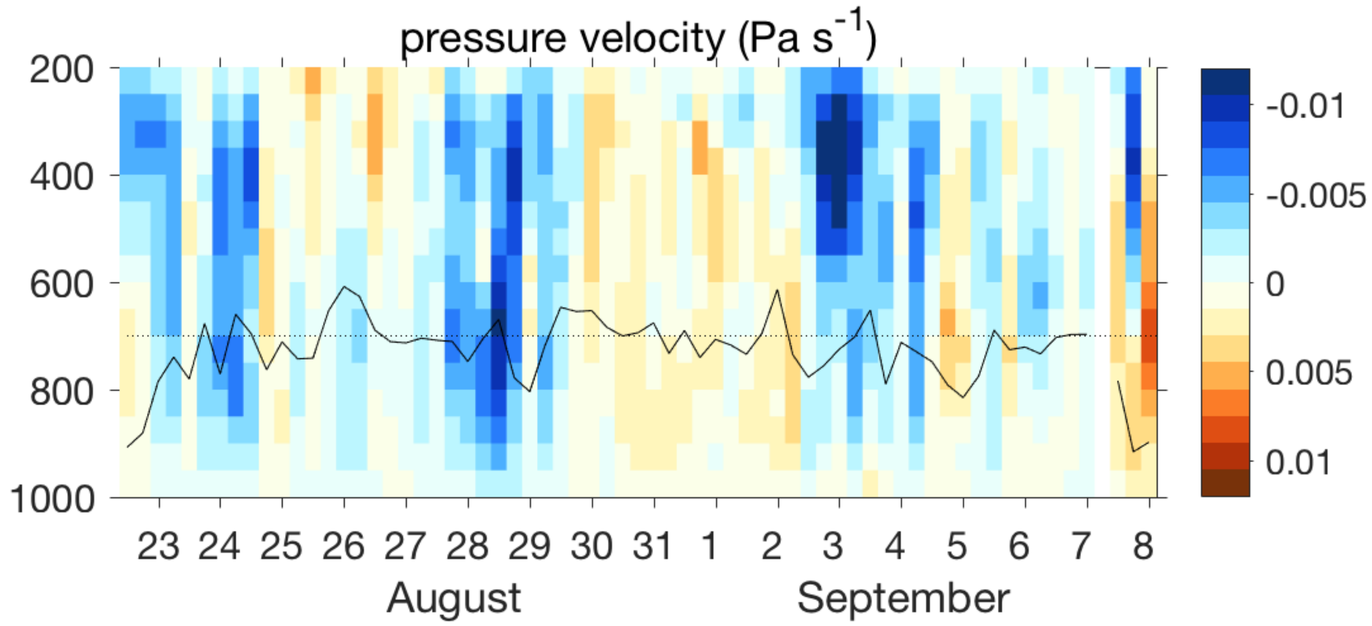
SEA-POL radar precipitating area



weights stratiform rain, lagging upward motion

Turbulence observations in stratiform rain

Large-scale vertical (pressure) velocity



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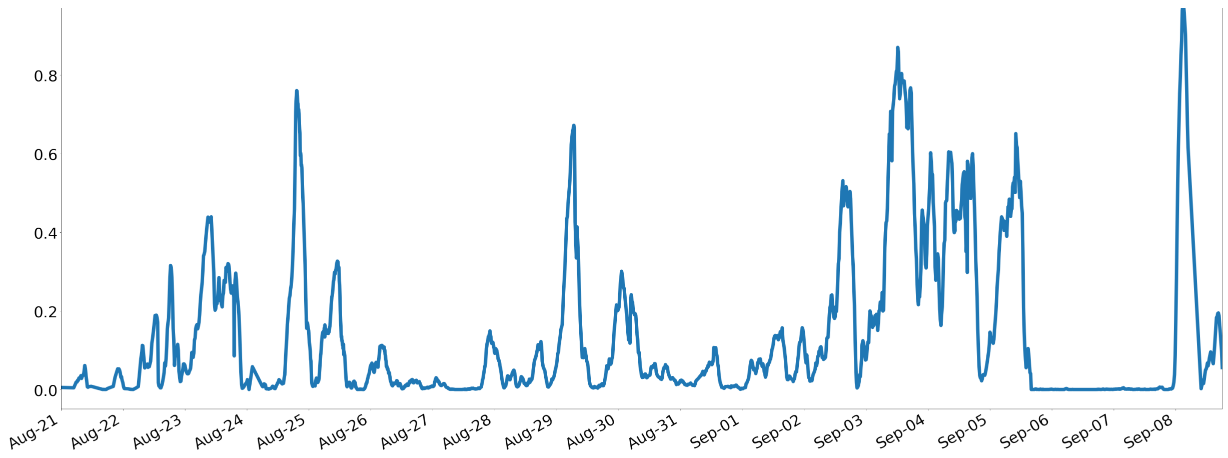
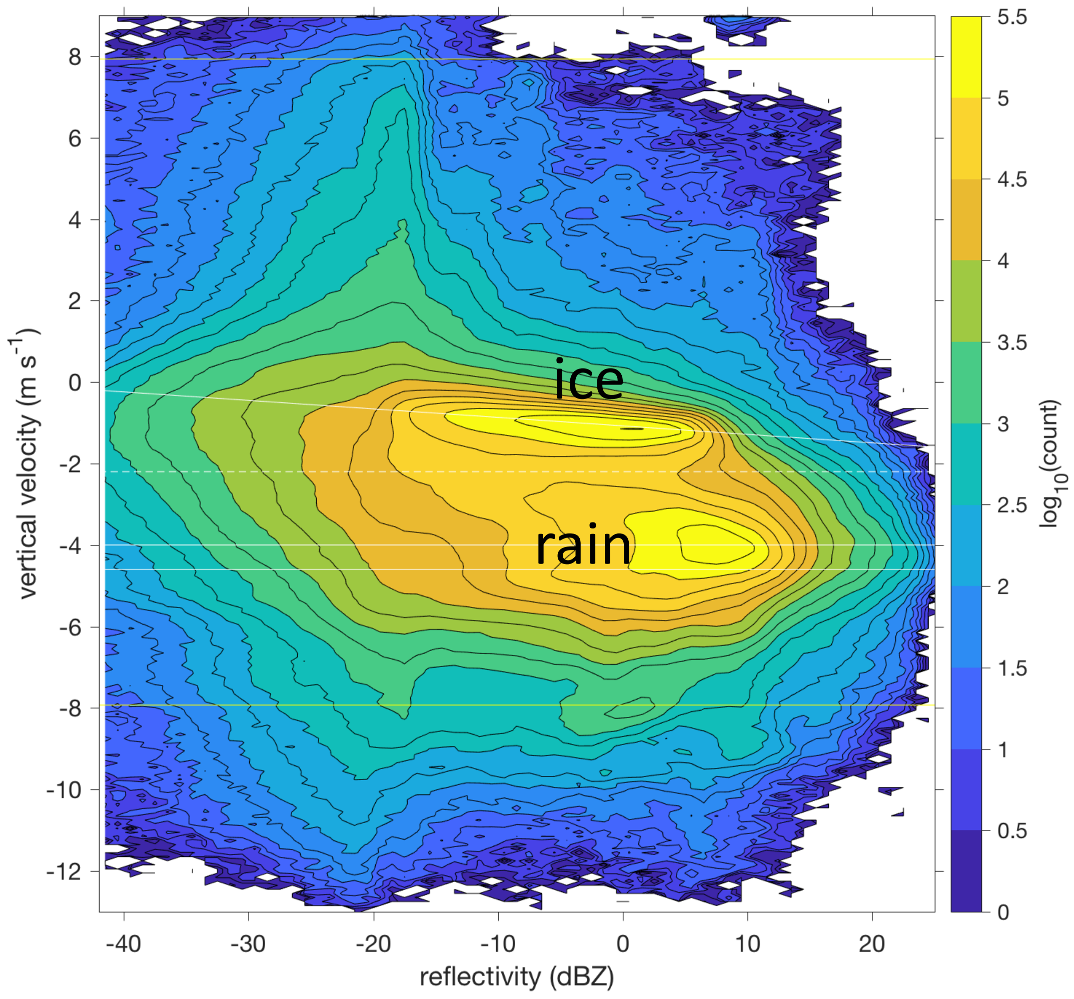


weights stratiform rain, lagging upward motion

Doppler cloud radar measures hydrometeors settling at 0-4 m/s



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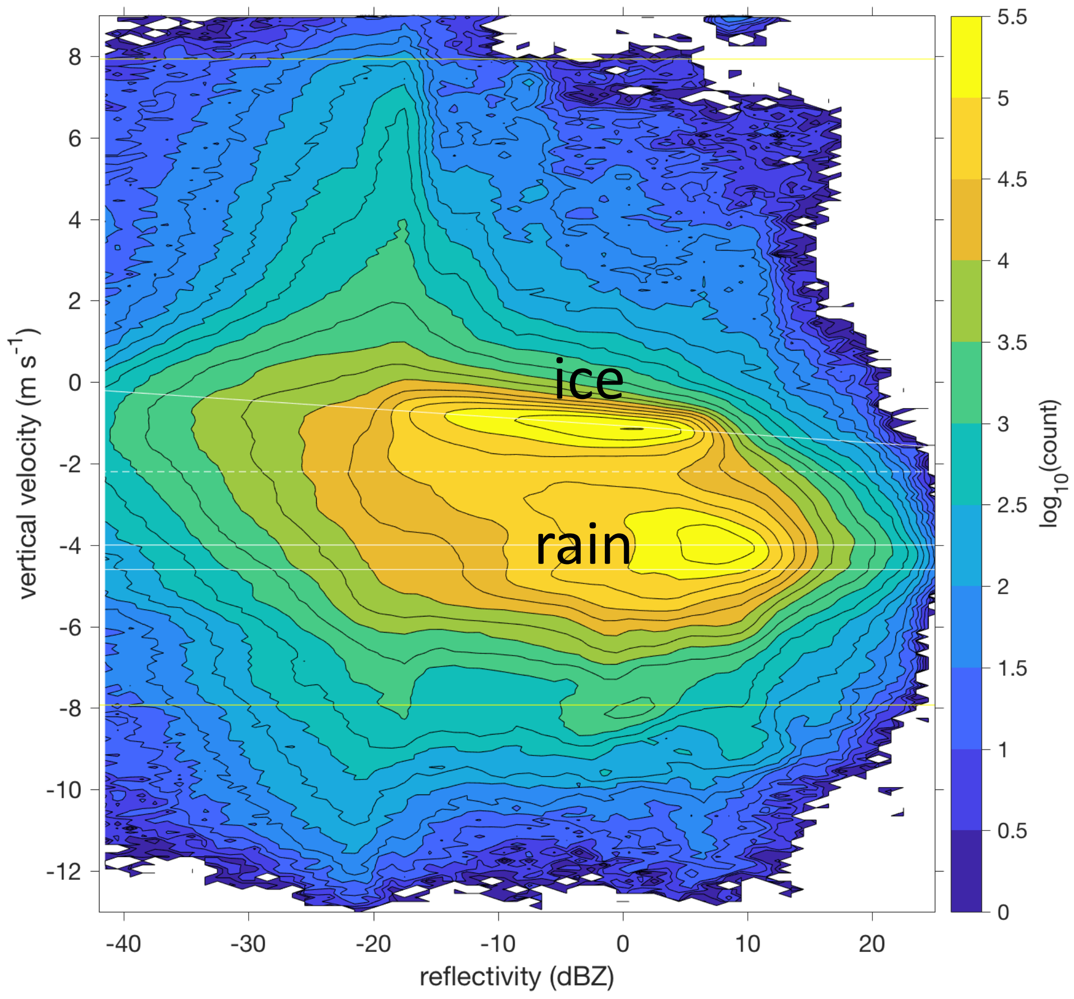
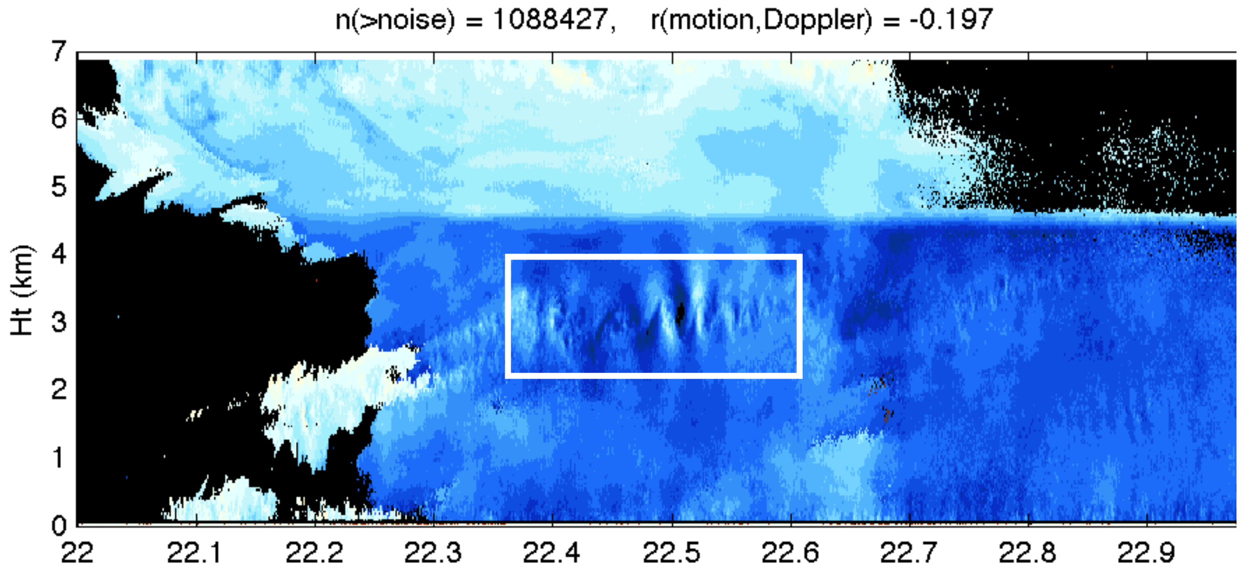


examples:

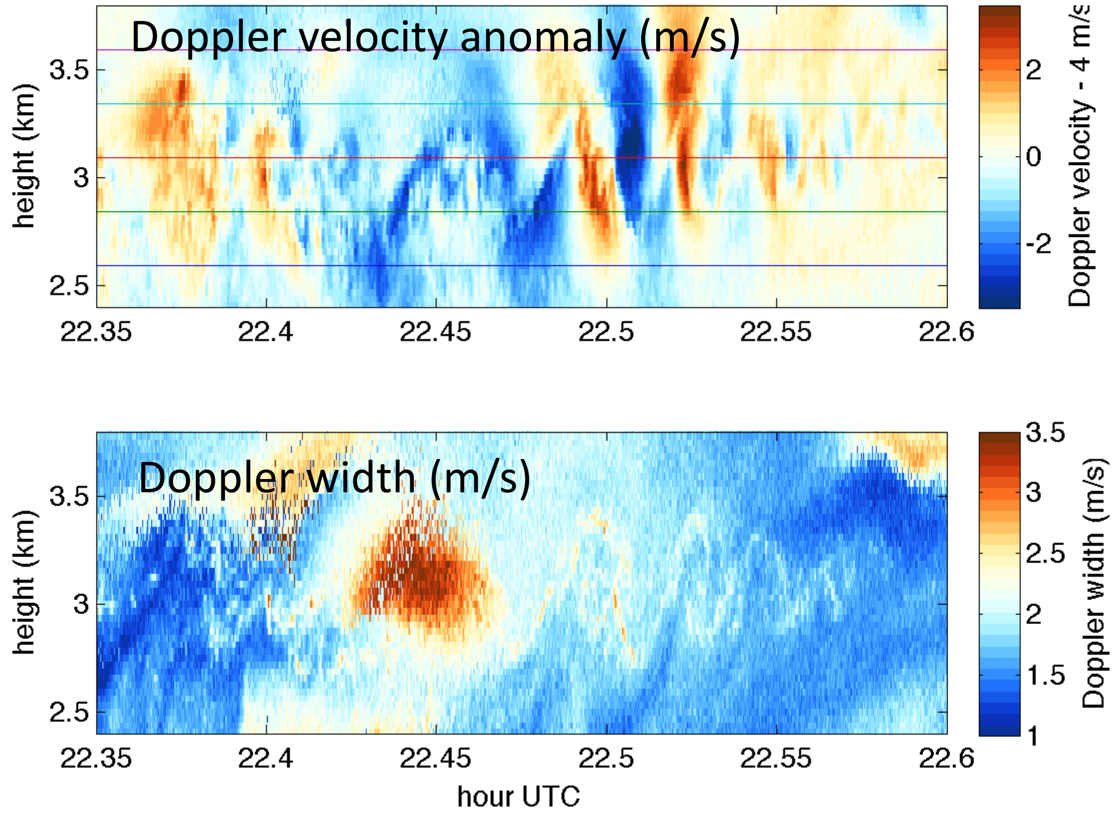
- Kelvin-Helmholz billows in stratiform rain
- Entrainment at the base of a cirrus cloud

Turbulence observations in stratiform rain

Cloud or precipitation makes air velocity detectible to Doppler radar.

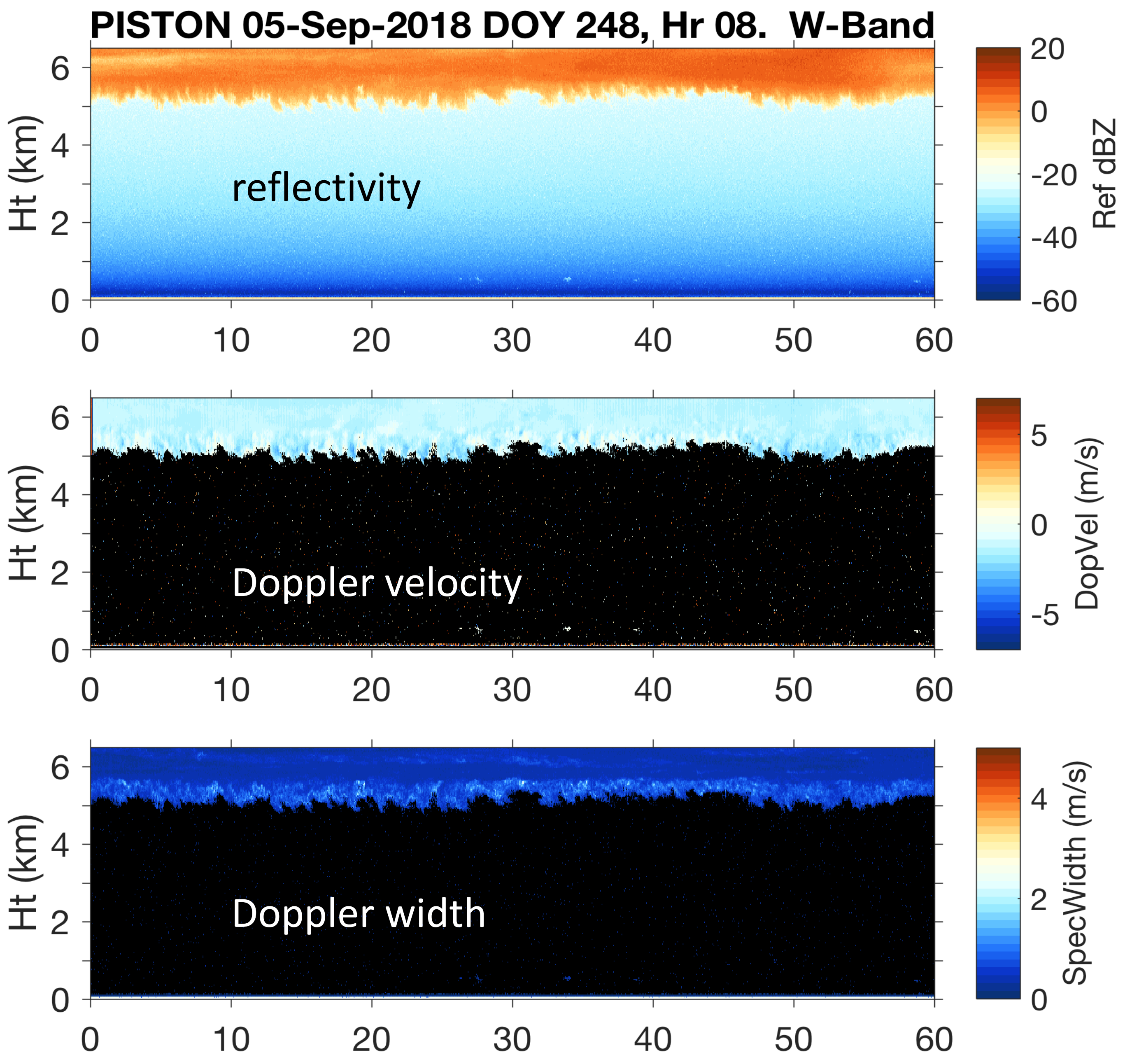


Kelvin-Helmholtz billows



Turbulence at a cirrus cloud base

- Eddies at ~5 km cirrus cloud base



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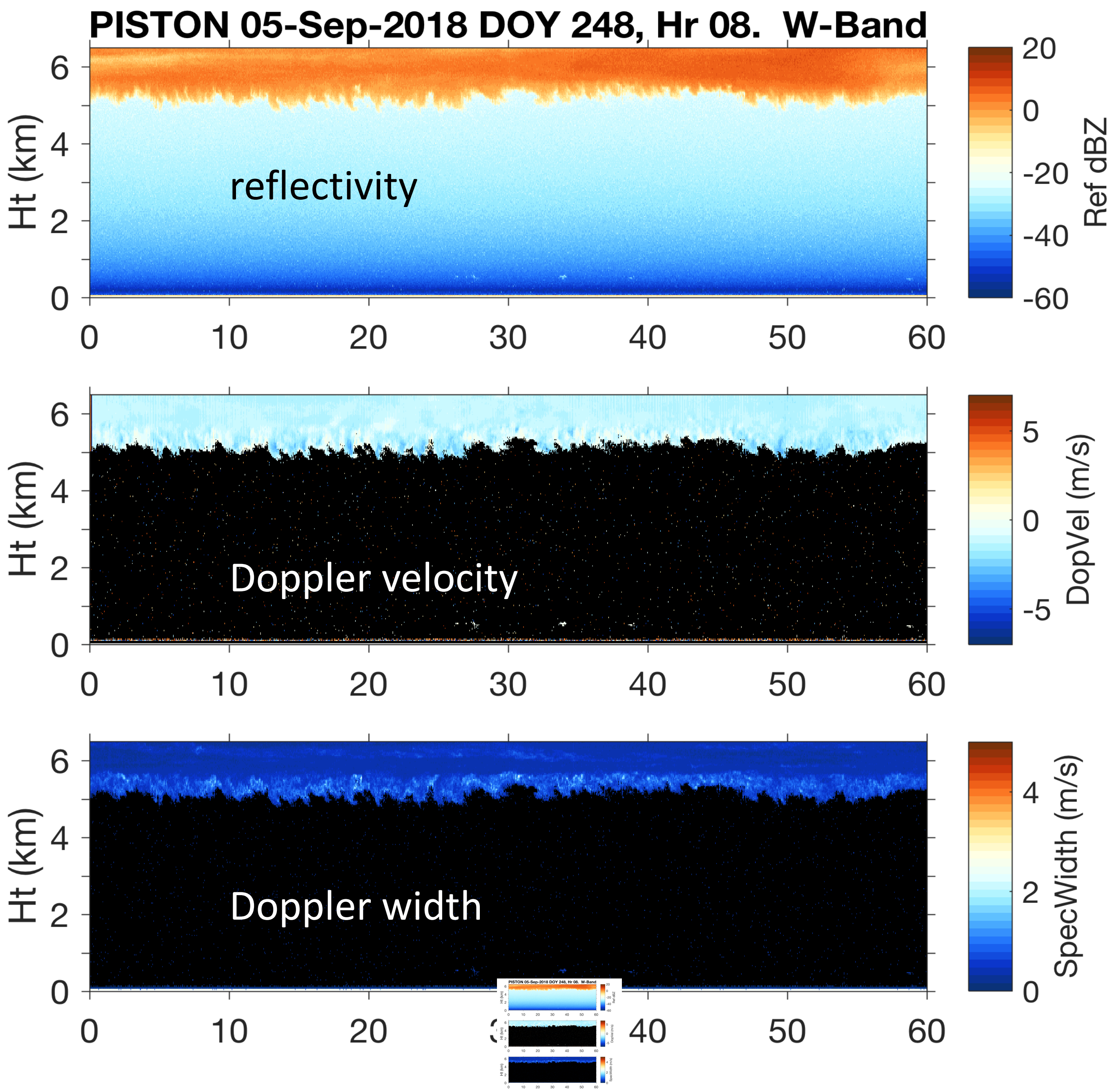
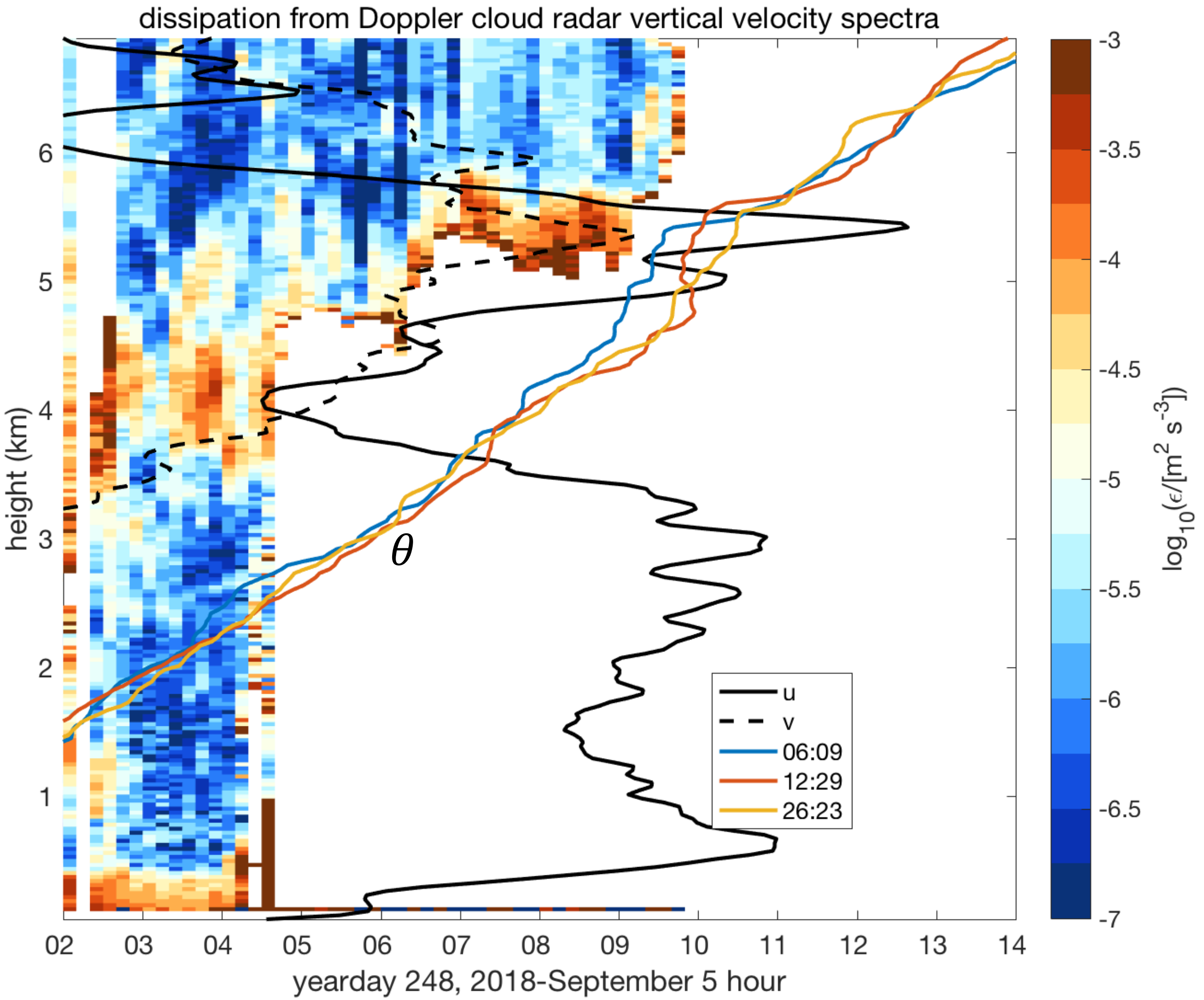


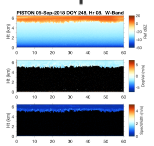
Turbulence at cirrus layers

- Eddies at ~5 km cirrus cloud base
- Mixed potential temperature layer.
- Strong wind shear.
- Strong dissipation

(September 5, as in HSRL)



sounding time



Turbulence at cirrus layers

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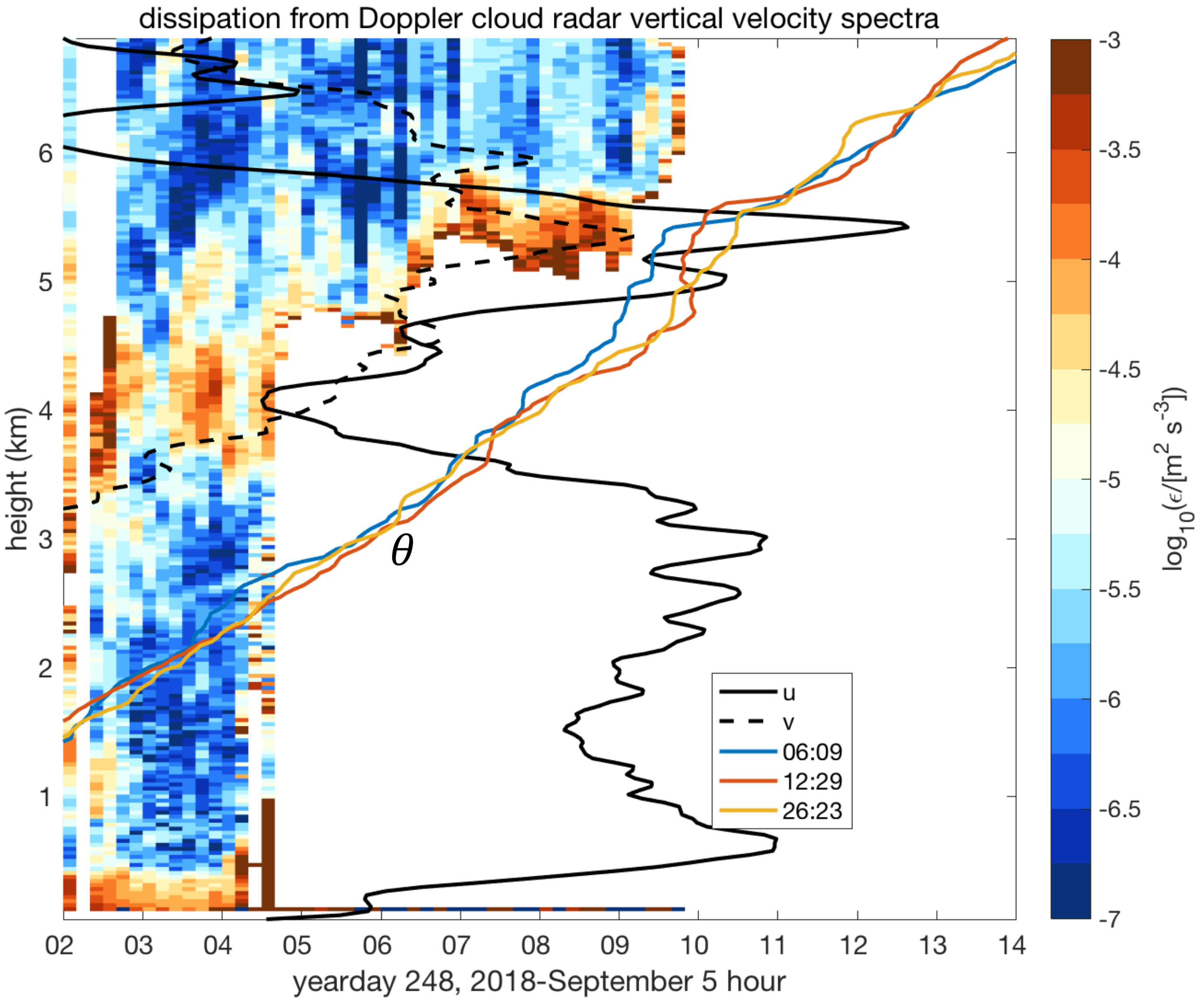
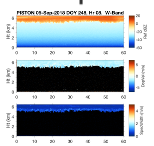
- Mixed potential temperature layer.
- Strong wind shear.
- Strong dissipation

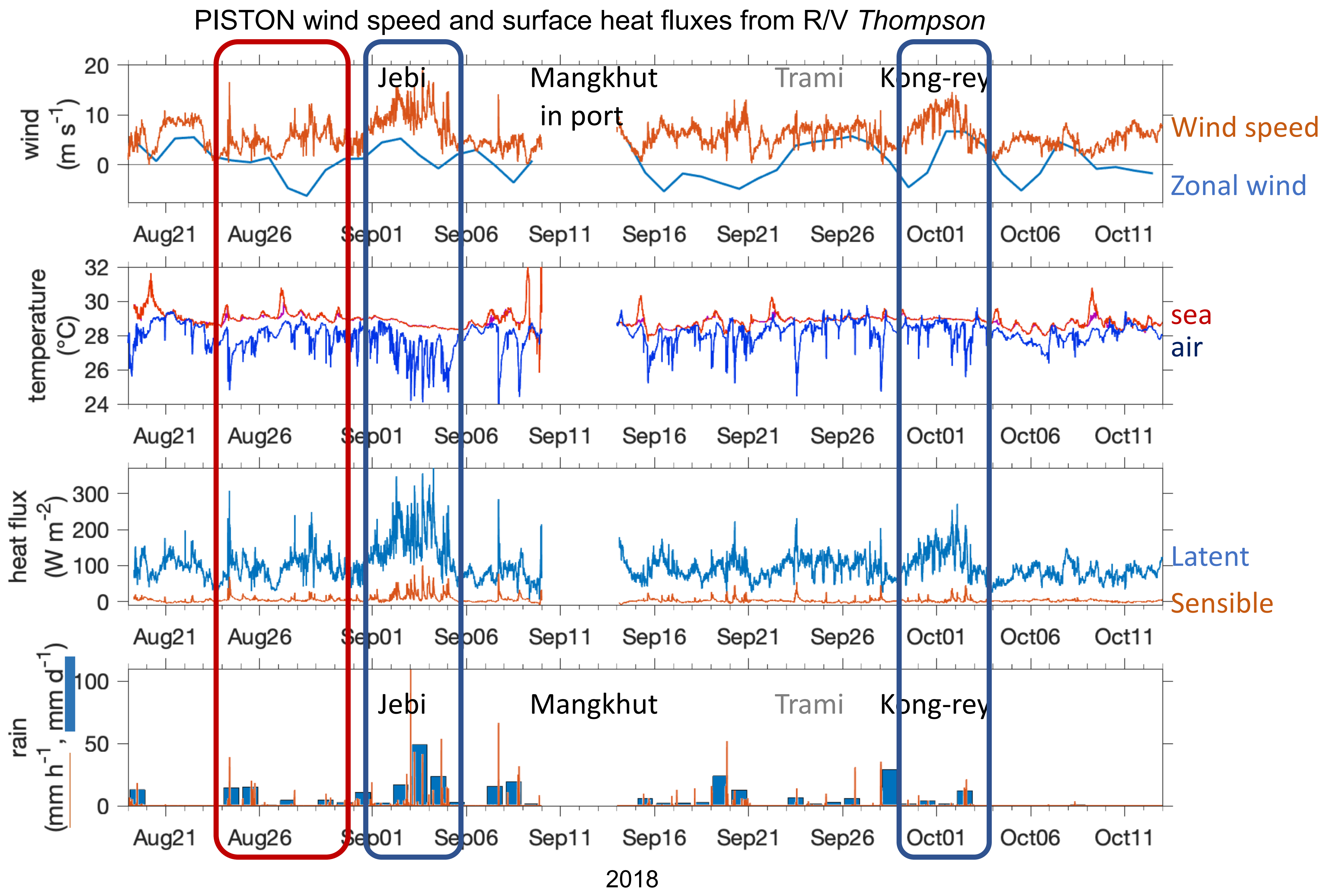
- 500-m surface mixed layer

(September 5, as in HSRL)



sounding time





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Jebi
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Wind speed
Zonal wind
wind (m s-1)
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Aug21
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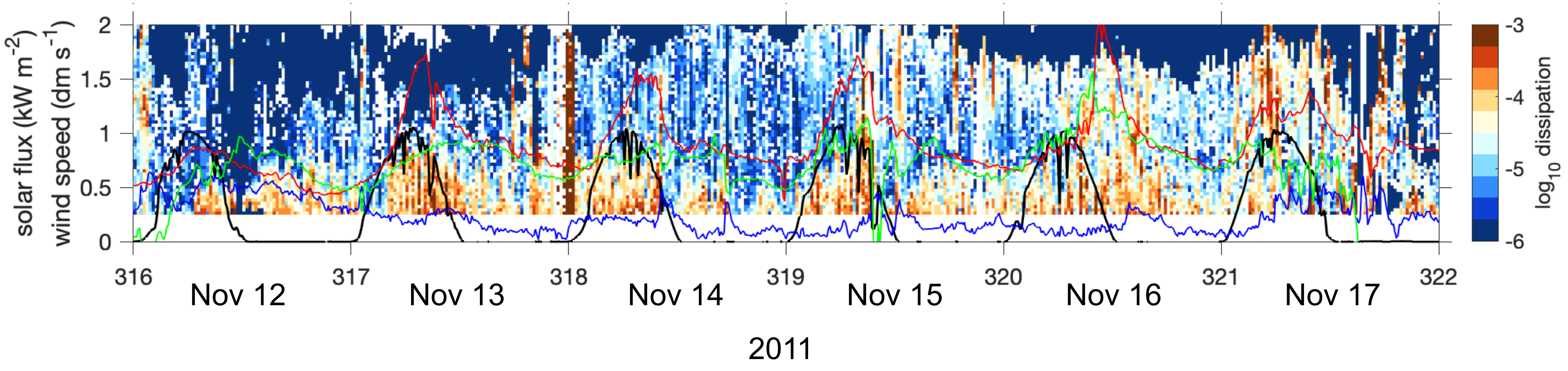
2018

Marine atmospheric sub-cloud mixed layer

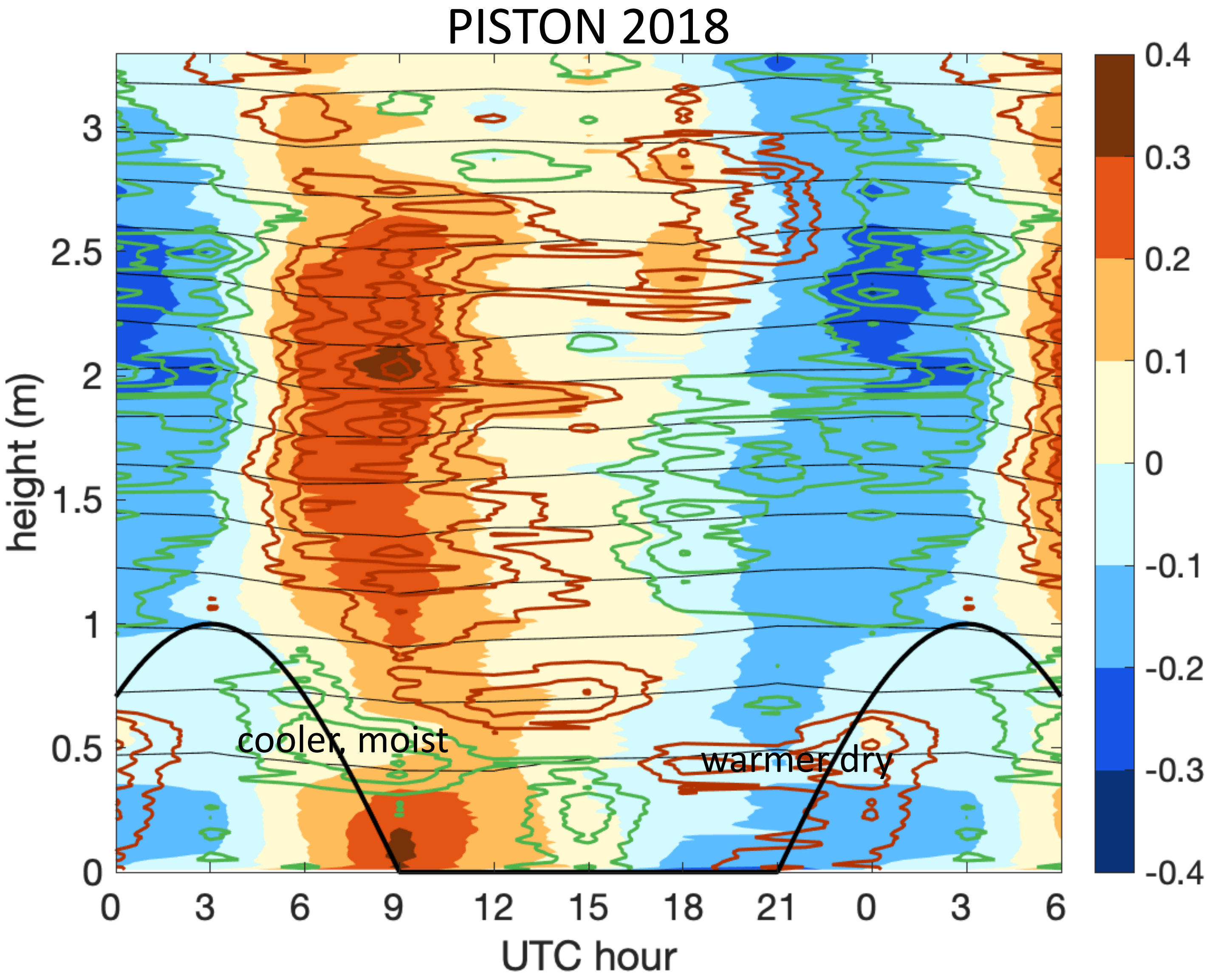
Doppler lidar shows
diurnal turbulence dissipation over strong diurnal SST

NOAA Doppler lidar vertical velocity dissipation in DYNAMO



Diurnal temperature and humidity:

0.5-3 km shallow cumulus convection coupled to sub-cloud ML



potential temperature (K)

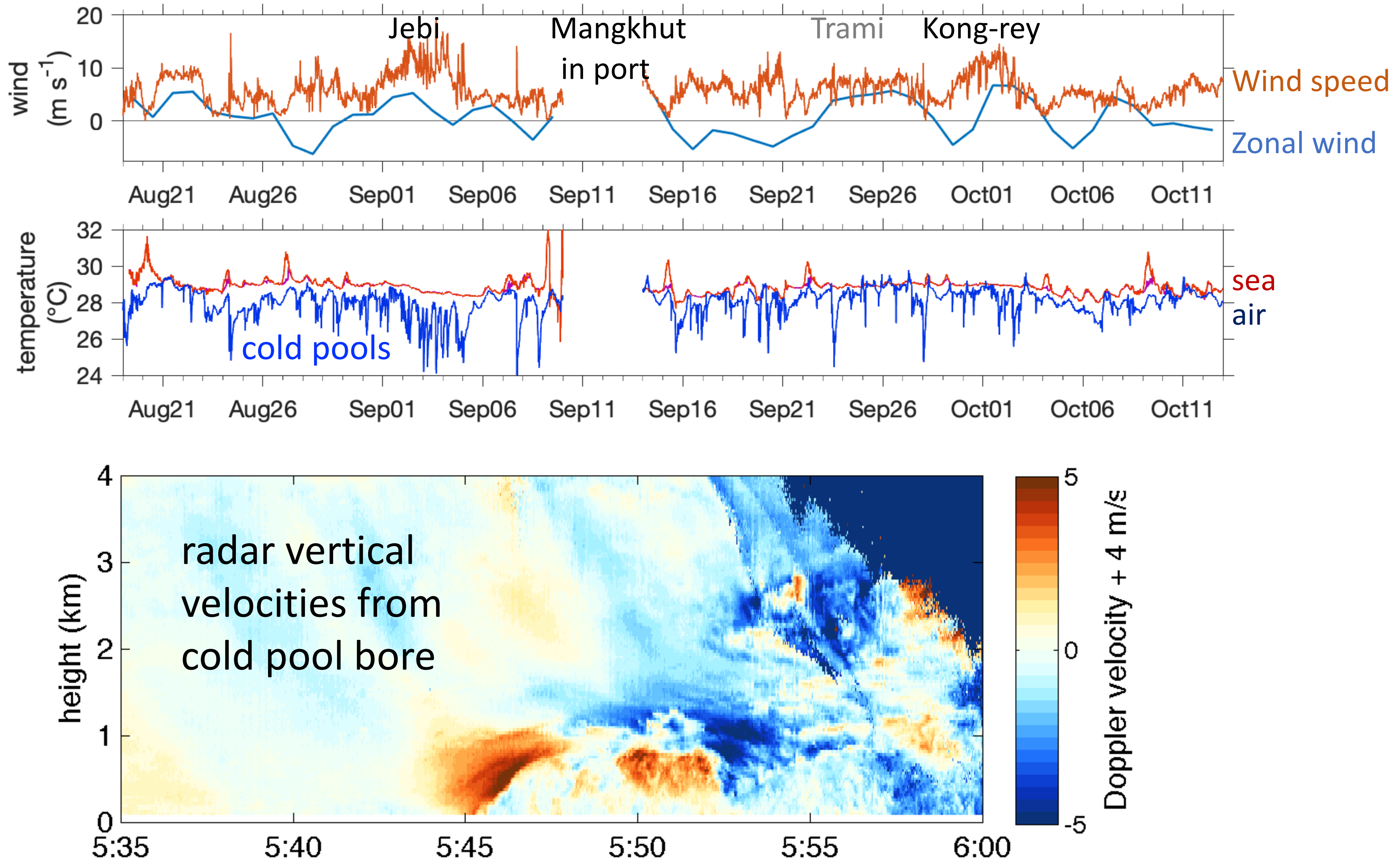
specific humidity

+0.1 g kg^{-1}

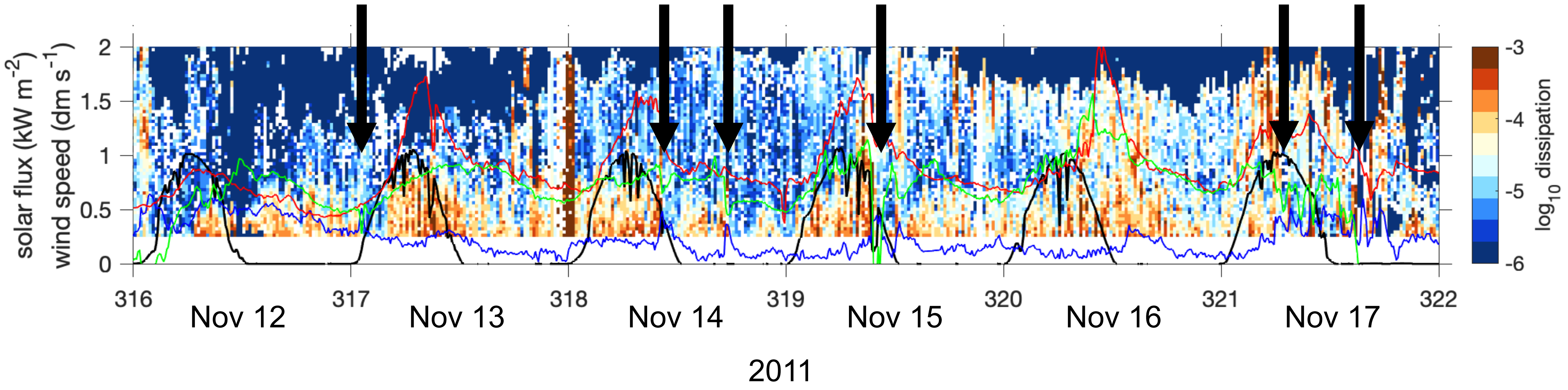
+0.1 g kg^{-1}

Cloud base diurnal T'
compensated by
deepening subcloud BL

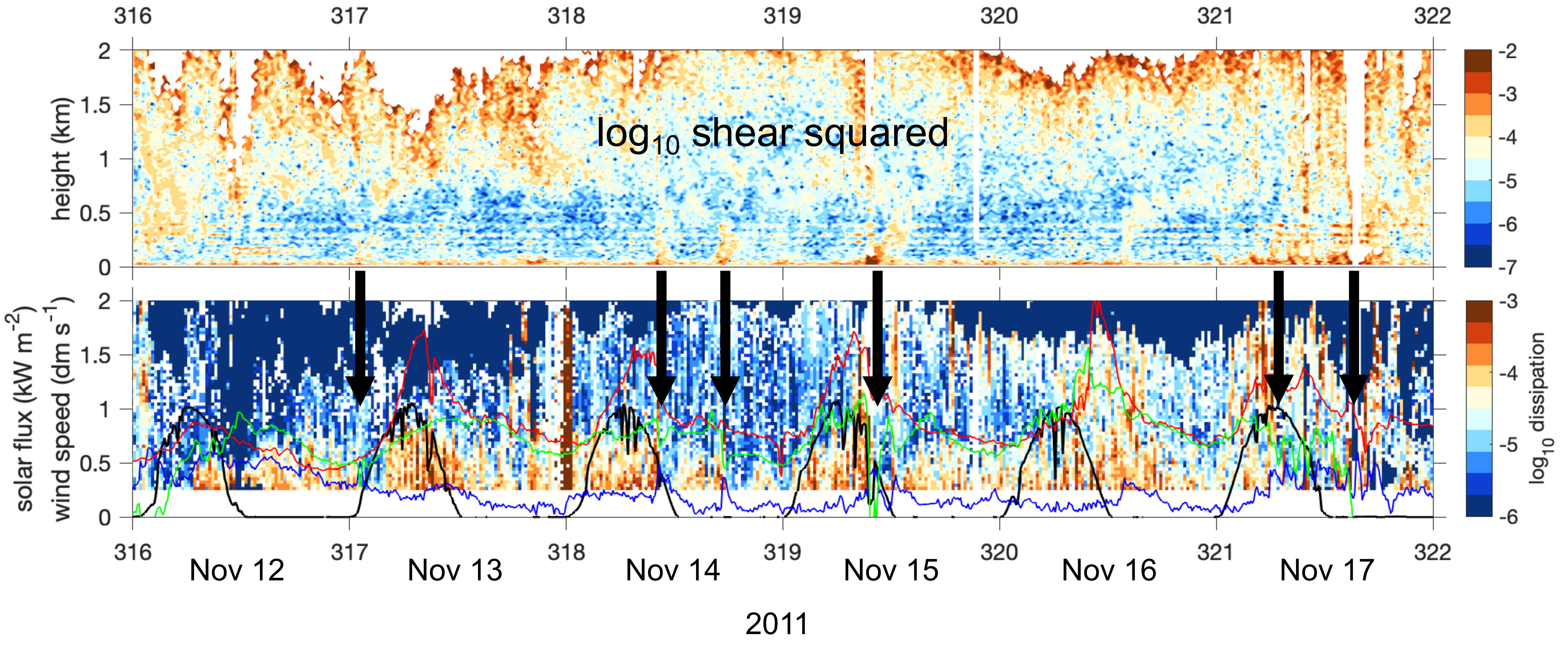
PISTON wind speed and surface heat fluxes from R/V *Thompson*



Cold pools interrupt mixing



Cold pools interrupt mixing and increase wind shear



Summary 1: surface fluxes

Wind from tropical cyclones, monsoon tails, and Kelvin waves:

- Enhances surface stress, heat, evaporation, and buoyancy flux
  - in both the ocean and the atmosphere.
  - Buoyancy flux is discontinuous across the interface, since ocean and atmosphere have different equations of state.
- Wind maintains mixing in the upper ocean.

Calm periods allow the surface few meters of the ocean to warm.

- The warm SST enhances buoyancy flux into the atmosphere, coupling to shallow cumulus cloud mixing over 0-3 km.
- The ocean mixes the warming down at night (buoyancy flux into the ocean).

Summary 2: remote sensing of turbulence

- Lidar and radar observe turbulence, shear, turbulent kinetic energy, and its dissipation.

- Diurnal atmospheric surface mixed layers are observed for weak winds over diurnal warm layers.
  - Ocean and atmosphere have opposite buoyancy mixing-stratification diurnal cycles.
- Cold pools stratify the surface layer, enhance shear, and suppress turbulence.
  - Cold pools cool and dry the subcloud mixed layer.