Short-lived anomalies of hydrophysical characteristics at the continental slope off the Russian coast in the northwestern Japan/East Sea from spring through early fall

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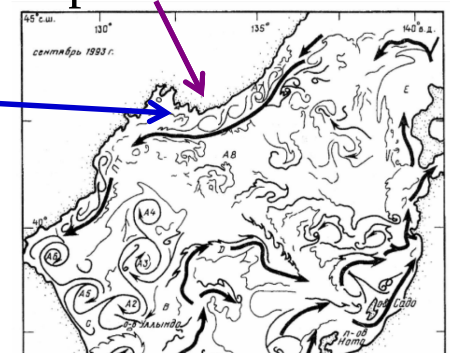
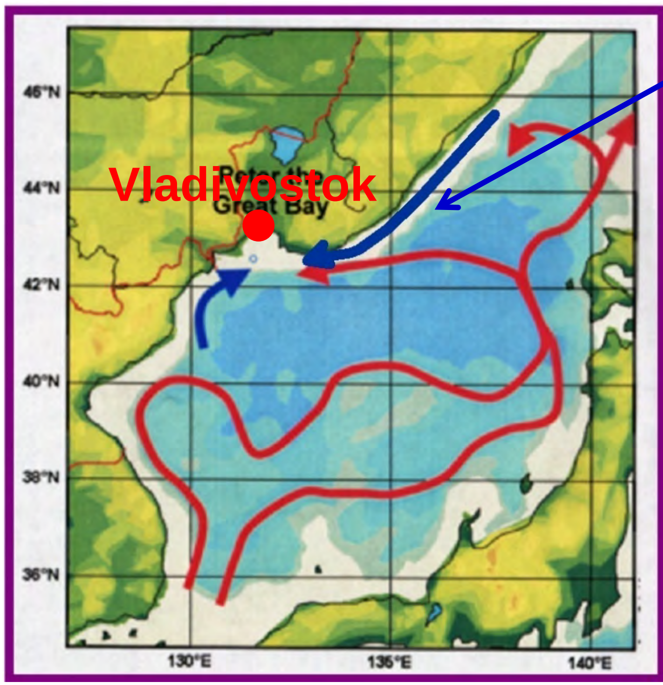
Background: the dynamically active zone within the Primorye (Liman) Current in the northwestern Japan Sea

Primorye Current area

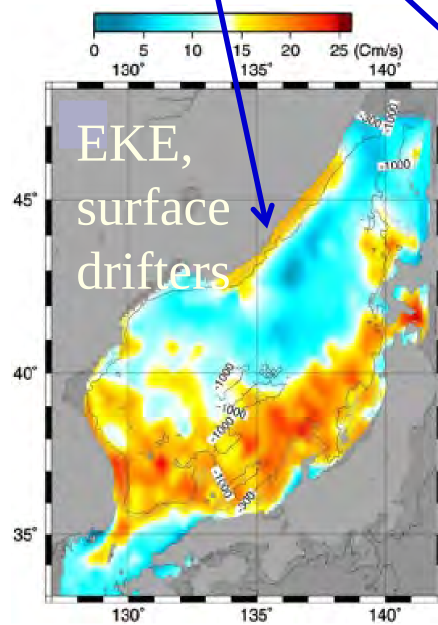
Slope eddies



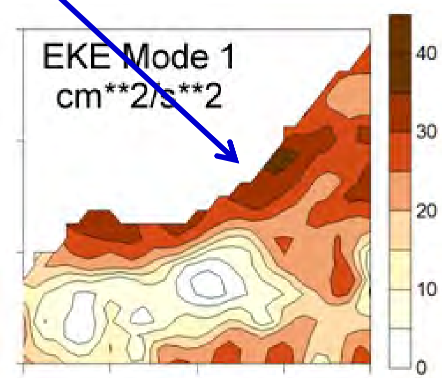
Satellite IR imagery (Ginzburg et al., 1998)



Slope eddies, shelf waves, alien water intrusions with eddies, streamers, and filaments.

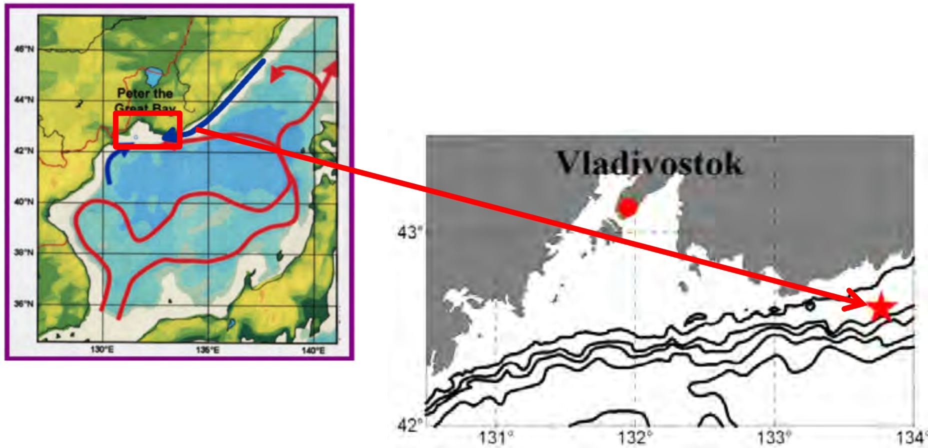


(Lee, Niiler, 2005)



Satellite altimetry, AVISO, 1993-2015 (Trusenkova, 2014)

To study the dynamically active zone within the Primorye Current



Aqualog moored profiler installed at the continental slope (42.5°N, 133.8°E), depth of 440 m. Unique data from April 18 through October 15, 2015 (half a year!).

Previous findings (Trusenkova et al., 2018).

Using HHT pycnocline displacements in the vertical were studied from depth changes of the 27.15 kg/m^3 isopycnal:

- fluctuations with periods of 2–3.5 and 8–13 days, of highly variable amplitudes were detected, which are within the life times of submesoscale and mesoscale eddies;

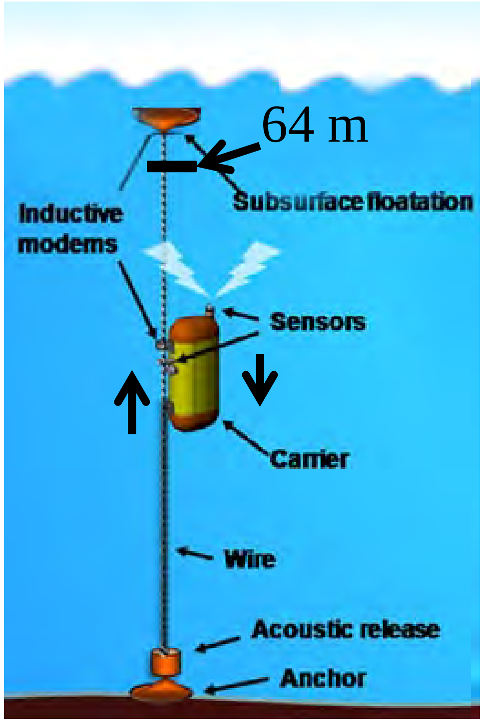
- more regular oscillations with periods of 18–22 days could be wave-like structures;

- the extremely strong oscillation with 1 month period was detected from mid April through late May (1.5 periods).

Purpose of the study

To continue the analysis of the Aqualog data and to consider variability of hydrophysical characteristics along the isopycnals.

Aqualog profiler



(Ostrovskii et al., 2013)

Period: April 18 through October 15, 2015.
Upward/downward casts 4 times a day, sampling every 0.2–1 m, from 64 through 300 m, every 6th day 64 through 420 m, below the seasonal pycnocline of the subarctic water structure.

Temperature, *conductivity and pressure* measurements by SBE CTD 52MP, currents by Nortek ACM Aquadopp.

Analyzed are time series with the 6 hour step:
- isopycnal depths for 27.05, 27.1, 27.15, 27.2, 27.25 kg/m^3 (D27.05–D27.25 within the 64–300 m layer);
- temperature at D27.05 – D27.25 (intrusion indicators);
- kinetic energy (per 1 m of depth and 1m^2) at D27.05–D27.25.

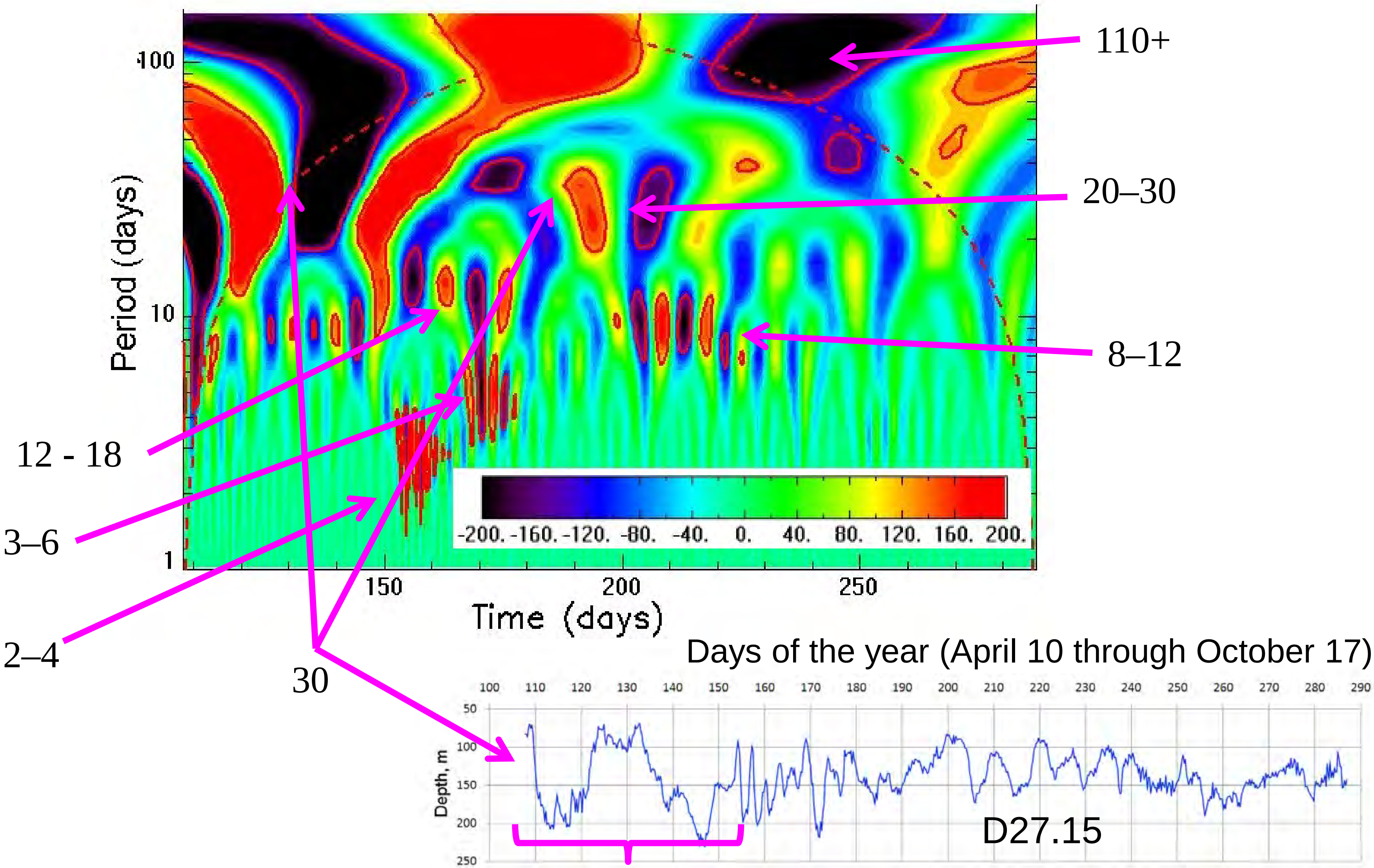
Satellite IR imagery

AVHRR/NOAA (IR; 1 km resolution);
VIIRS/Suomi-NPP (IR; 375 m resolution).

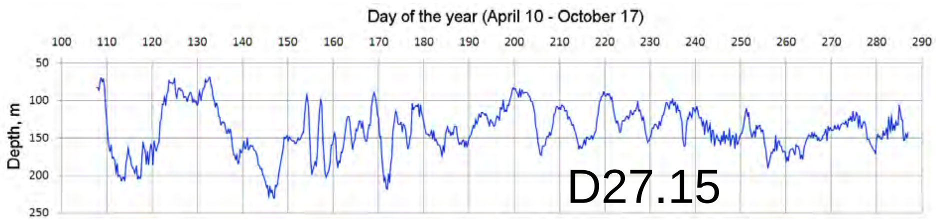
Checking time scales using the wavelet analysis

Time scales (days): non-stationarity

Wavelet transform of the D27.15 depth,
DOG-9 real mother wavelet



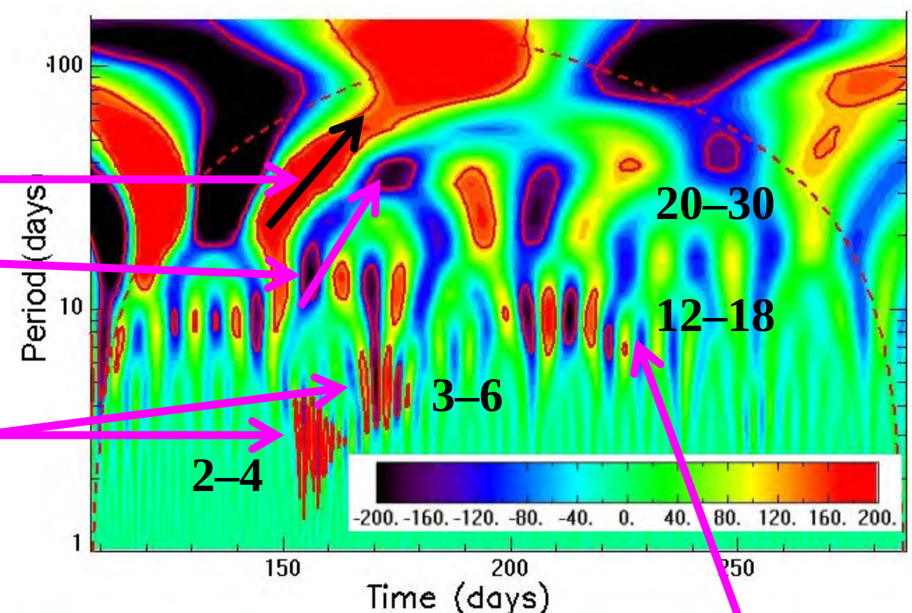
Time scale change



Wavelet transform of D27.15 depth, DOG-9 real wavelet

Early to mid June:
energy cascade from
20 – 30 days to 100+ days
12–18 days to 30 days

2–4 → 4–6 days



Late May:
1 month oscillation weakened.

Fluctuations weaken from mid August

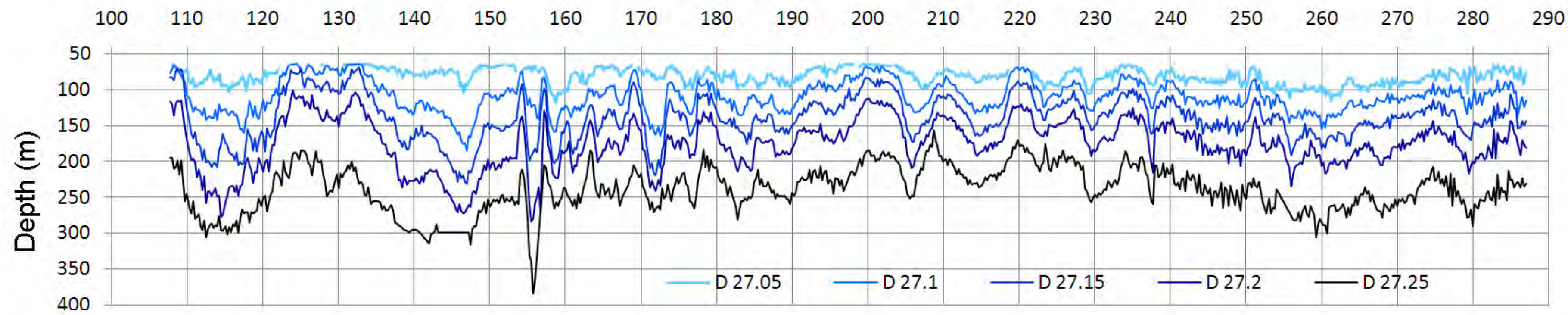
Regime change after the passage of the large eddy.

Estimation of fluctuation coherence through depth

Coherent pycnocline fluctuations in the vertical: depth of D27.05 – D27.25 (the 27.05 – 27.25 kg/m^3) isopycnals

(every 0.05 kg/m^3)

Days of the year (April 10 through October 17)



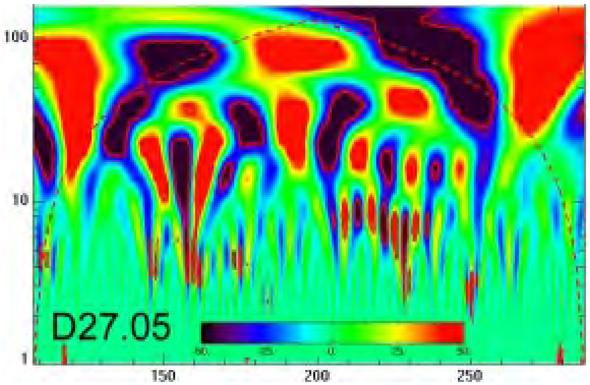
σ_θ	27.05	27.10	27.15	27.20	27.25
Mean	80.1	109.2	139.7	176.3	240.1
RMS	11.5	22.0	31.2	34.9	32.4

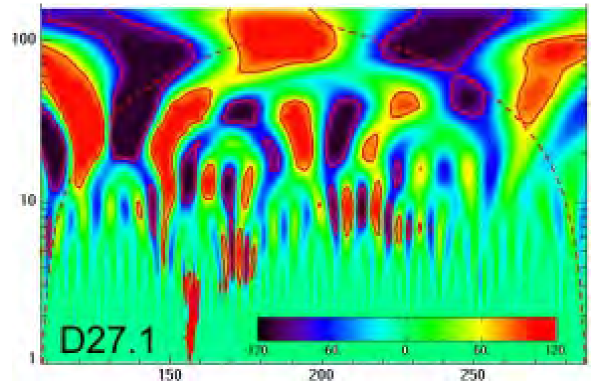
Correlations

σ_θ	27.05	27.10	27.15	27.20
27.10	0.71			
27.15	0.55	0.94		
27.20	0.44	0.85	0.94	
27.25	*0.35*	0.69	0.79	0.88

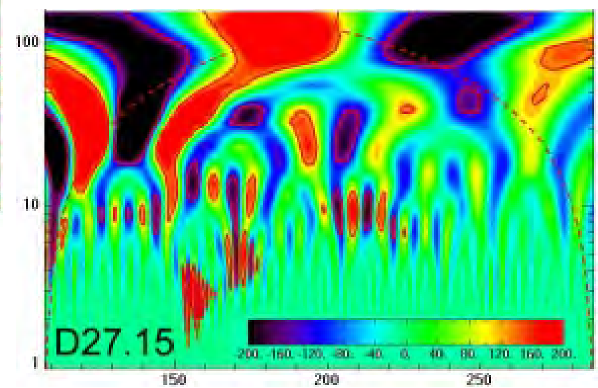
D27.15 – D27.25: the strongest fluctuations & coherence

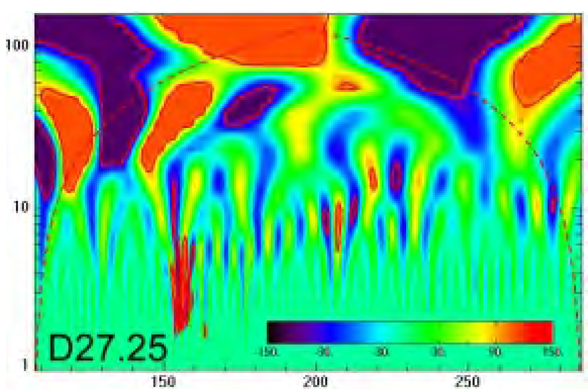
Coherent pycnocline fluctuations in the vertical: D27.05 – D27.25 depth, wavelet transform

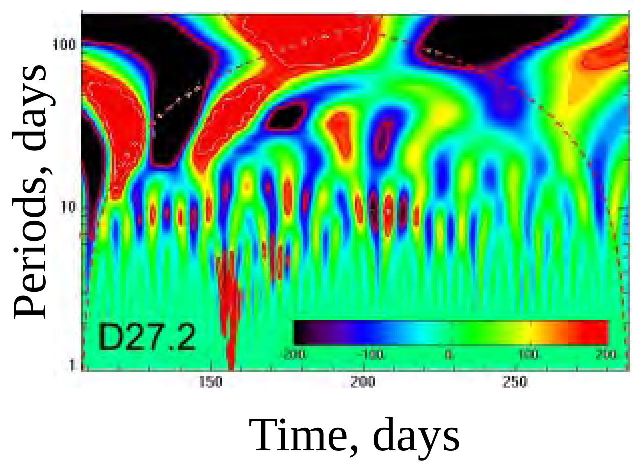




DOG-9 real mother wavelet



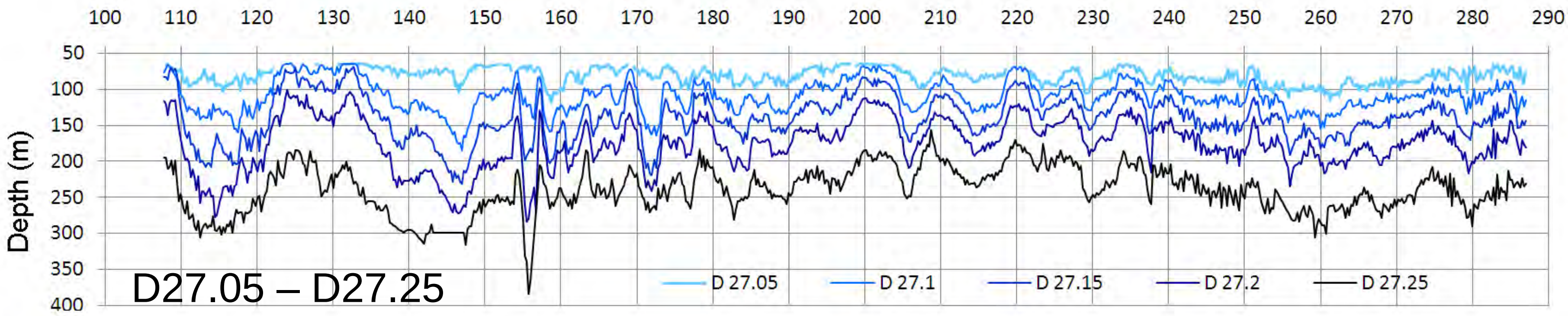




Very similar all but for D27.05

Isopycnal depth: coherent fluctuations weakening upward

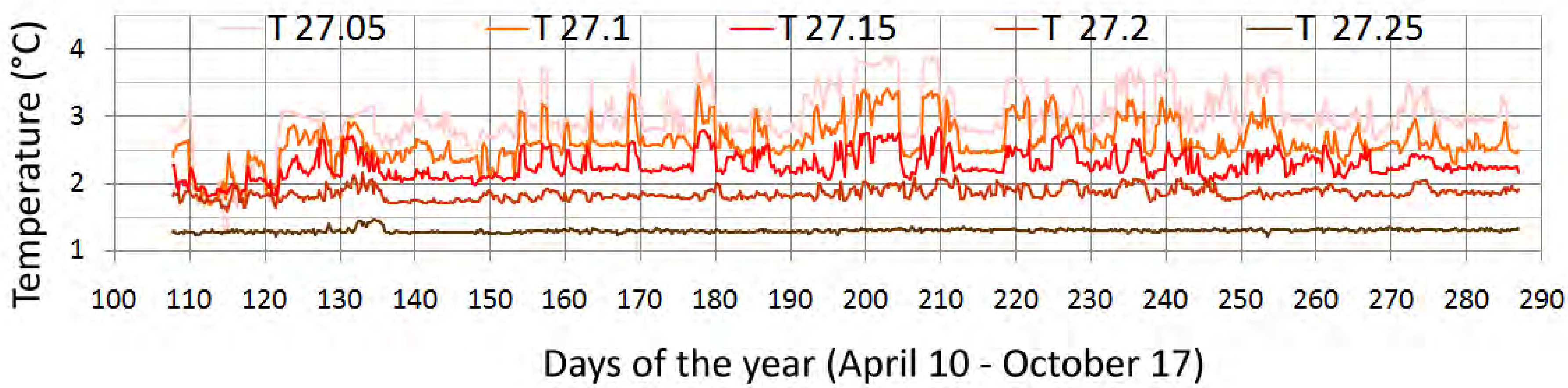
Days of the year (April 10 through October 17)



D27.15 – D27.25: the strongest fluctuations & coherence;
the signal does not come from the surface, it is probably advected.

Short-lived thermohaline anomalies at the isopycnals as indicators of alien water intrusions

Temperature (D27.05 – D27.25)



Shifts rather than oscillations (up to 1–1.5 °C) persist for 2–4 days.

σ_θ	27.05	27.10	27.15	27.20	27.25
Mean	2.97	2.62	2.27	1.85	1.30
RMS	0.43	0.31	0.20	0.09	0.03

Coherent T fluctuations at the upper isopycnals.

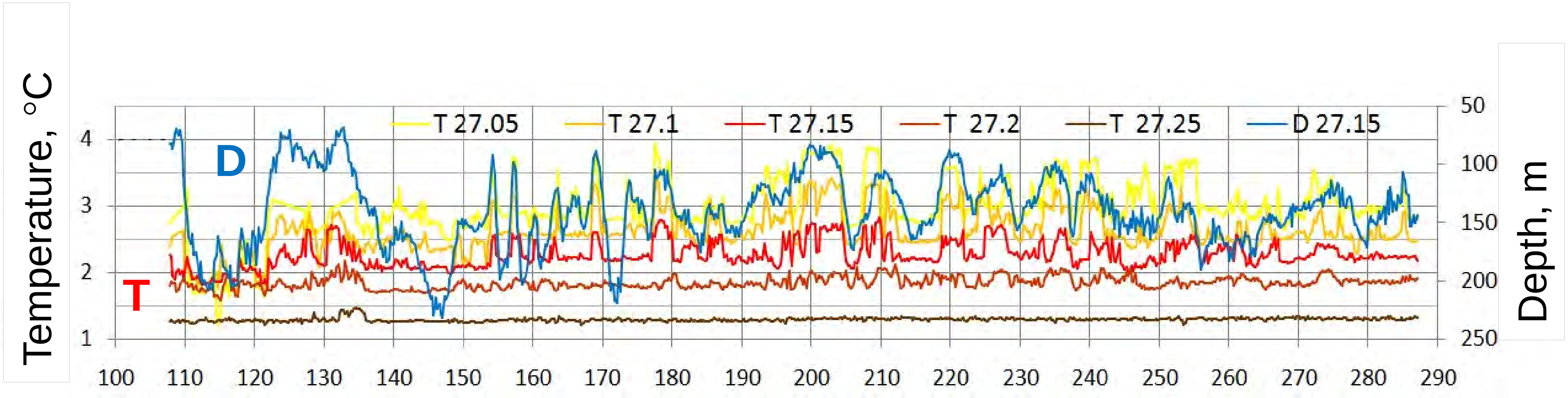
Correlations

σ_θ	27.05	27.10	27.15	27.20
27.10	0.83			
27.15	0.65	0.72		
27.20	*0.36*	*0.37*	0.46	
27.25	*0.18*	*0.14*	*0.2*	0.39

(T & S changes on isopycnals are coherent)

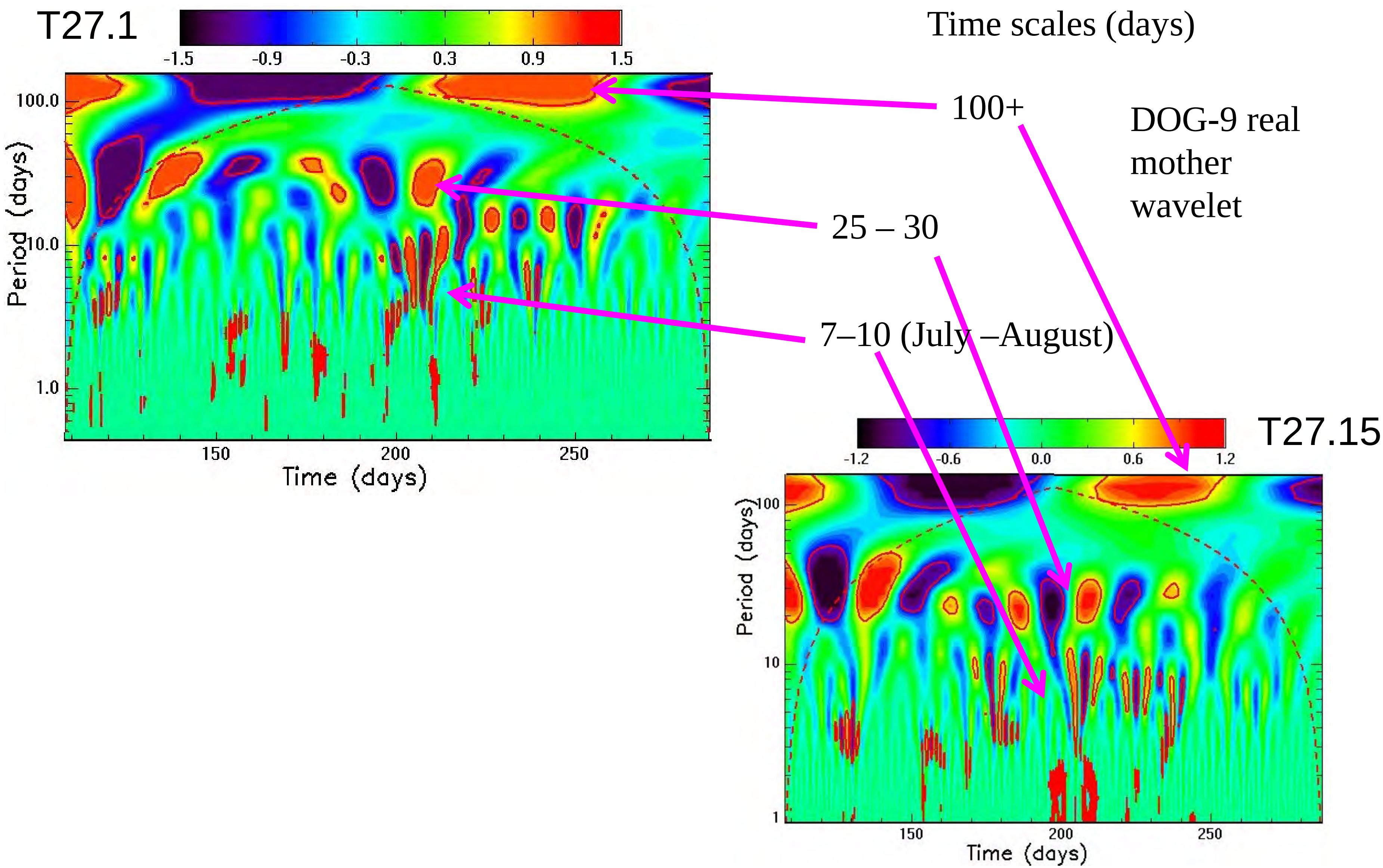
T on D27.05 – D27.25 isopycnals and D27.15 depth

D27.1 – D27.2: T tends to increase (0.5–1.5 °C)
with the isopycnal shallowing: R_{D-T}: -0.48 – -0.54.

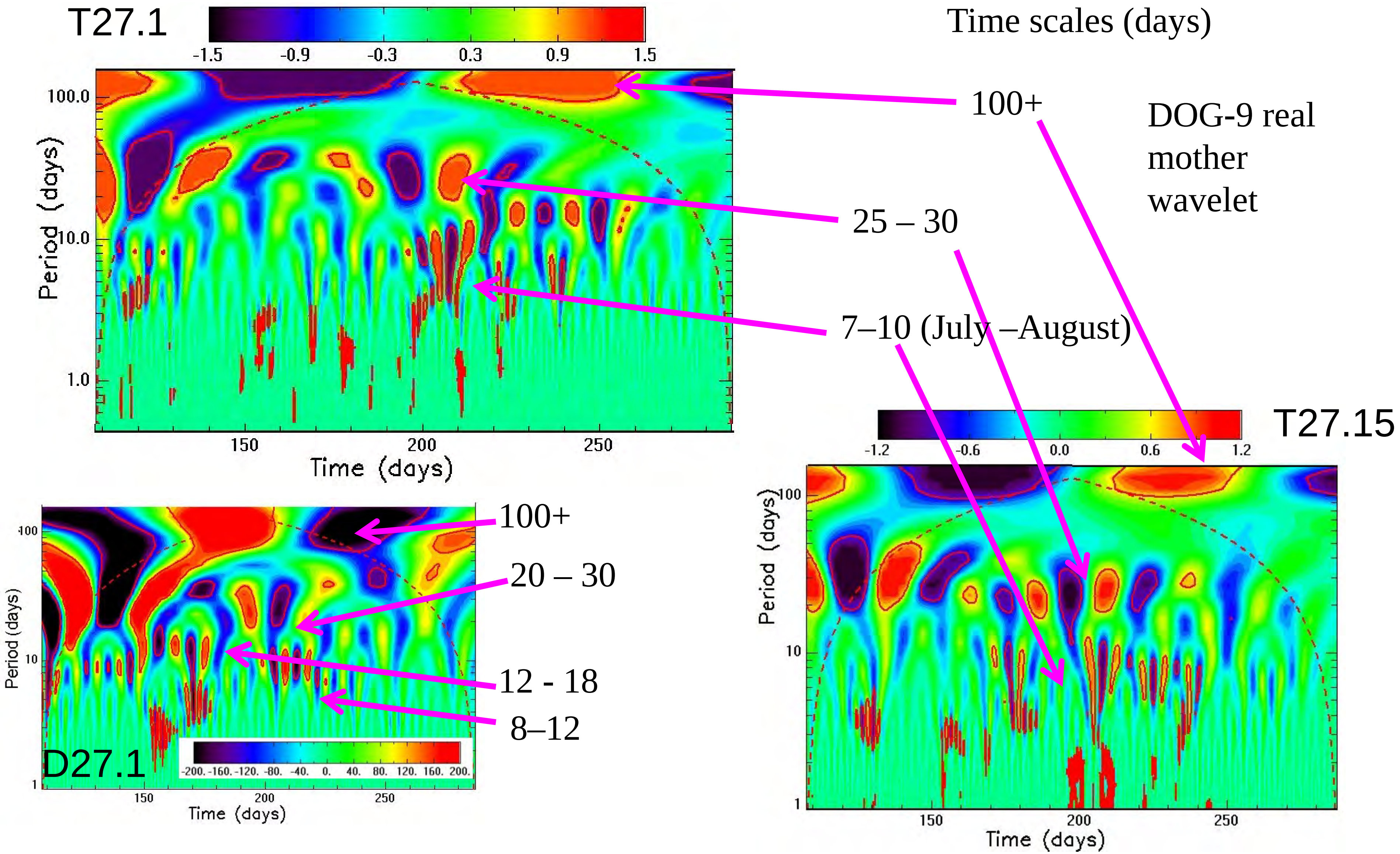


Days of the year (April 10 through October 15)

WT of T27.1 & T27.15: coherent fluctuations



WT of T27.1 & T27.15: coherent fluctuations



T vs. D: similar long periods, more regular 30 & 10 days fluctuations.

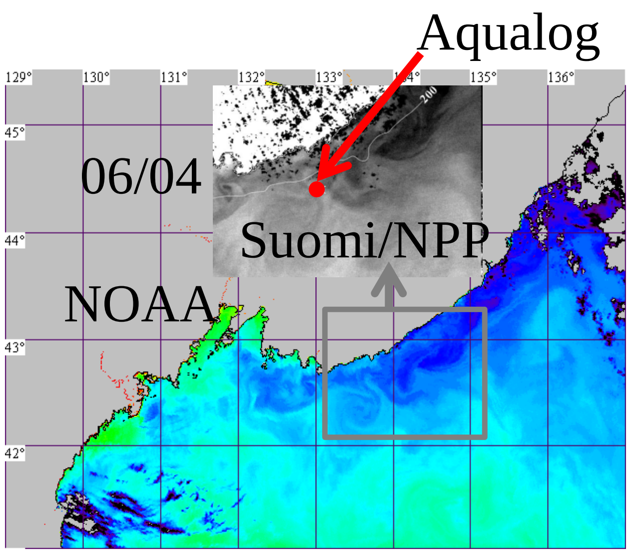
Linking local variability with dynamic structures detected on satellite imagery

Intrusions of several water masses (water exchange) were identified using satellite imagery, such as the Primorye Current water, coastal water, transformed subtropical water, upwelling water.

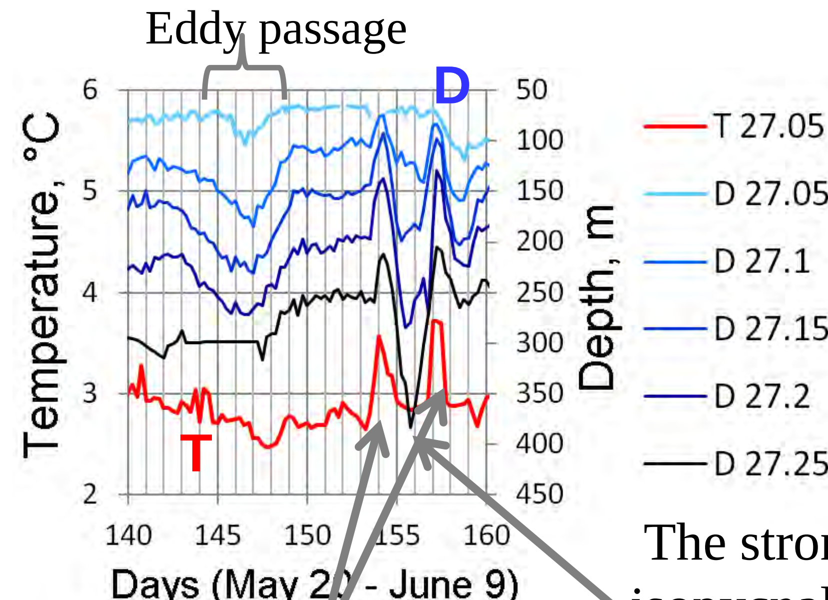
This deserves a special talk.

Here, just 2 examples.

Short-period fluctuations after the passage of a large warm eddy in early summer



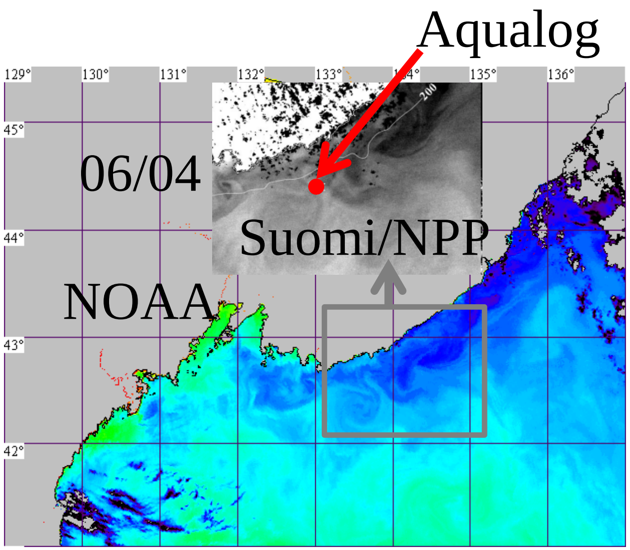
Warm eddy core passed the Aqualog site on May 26-27 (Lazaryuk et al., 2017): almost no T changes along the deepening isopycnals.



Isopycnal shallowing and T increase: June 3 and 6.

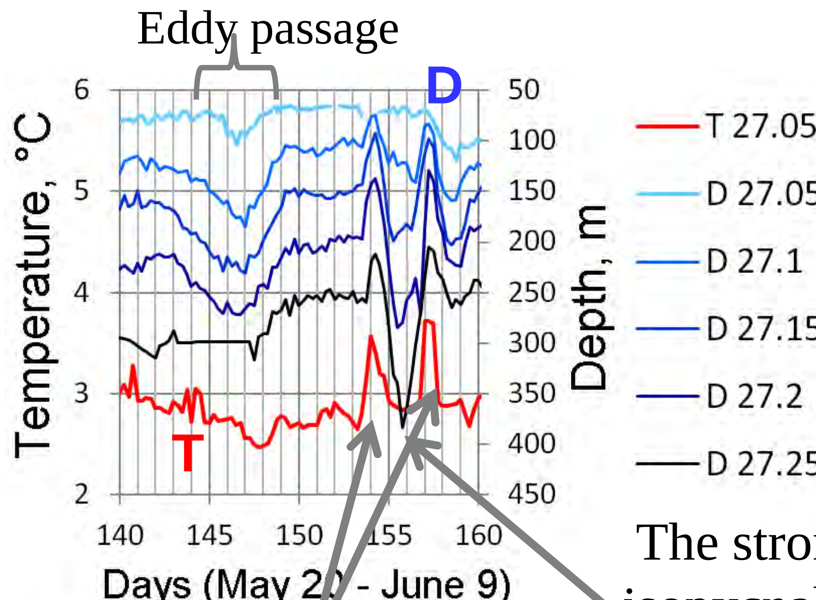
The strongest isopycnal drop on June 4–5.

Short-period fluctuations after the passage of a large warm eddy in early summer



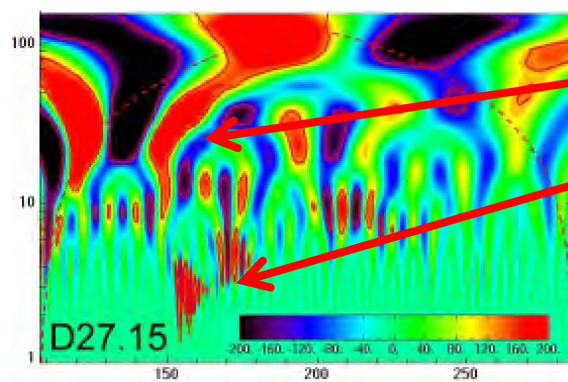
Warm eddy core passed the Aqualog site on May 26-27 (Lazaryuk et al., 2017):
almost no T changes along the deepening isopycnals.

T anomalies on the isopycnals: at the edges of large structures.



Isopycnal shallowing and T increase: June 3 and 6.

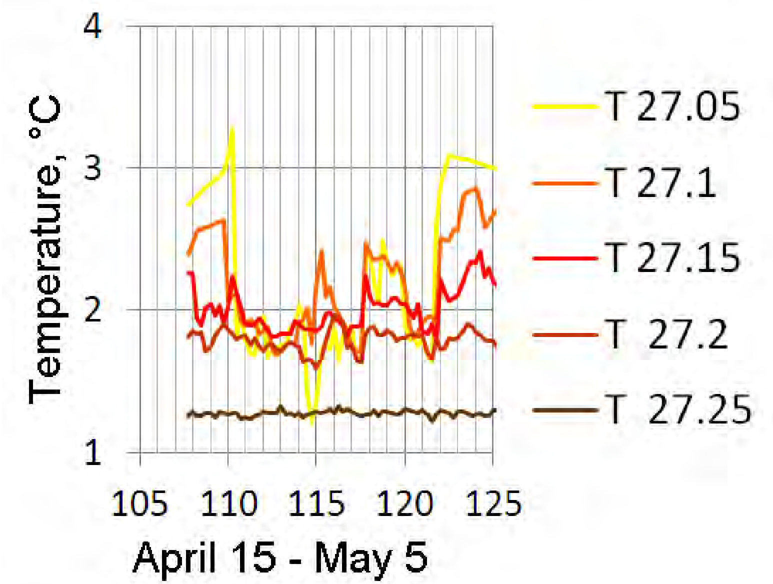
The strongest isopycnal drop but no T change: June 4–5.



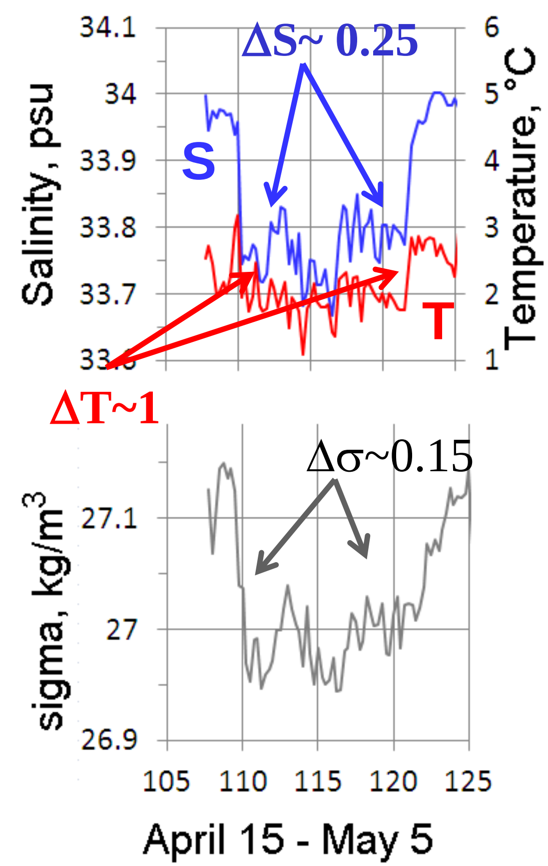
Energy cascade & time scale increase: regime change after the passage of the large eddy.

Thermohaline anomalies from April 21 through May 1 due to the offshore intrusion of the Primorye Current

T at the isopycnals



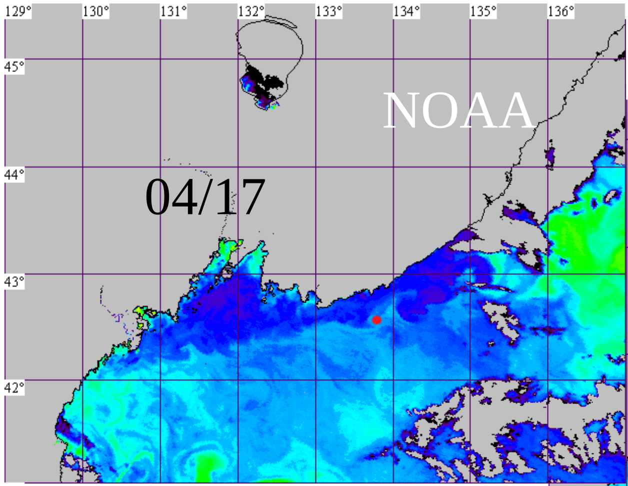
T, S, sigma, 64-70 m

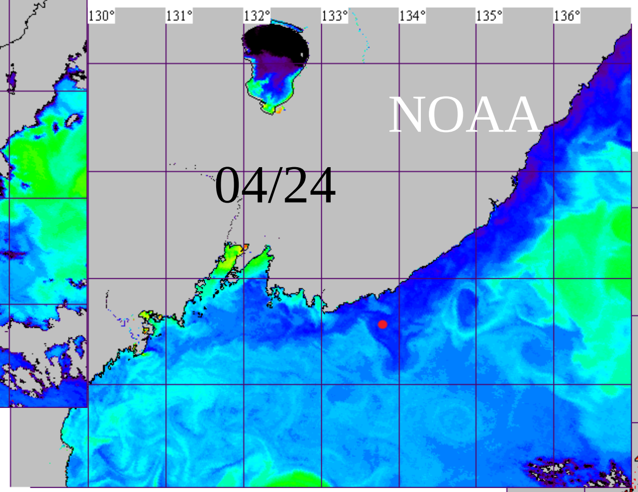


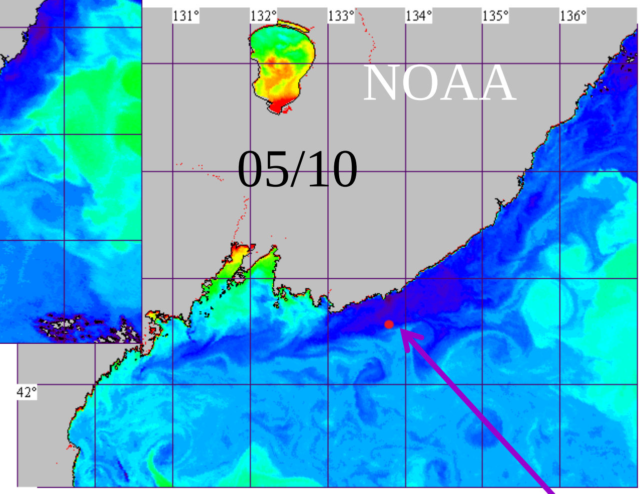
T in the 64–70 m layer is less than at the 150–200 m depth and in some days less than at the 250 m depth.

Density stratification is kept by salinity.

Primorye Current offshore excursion



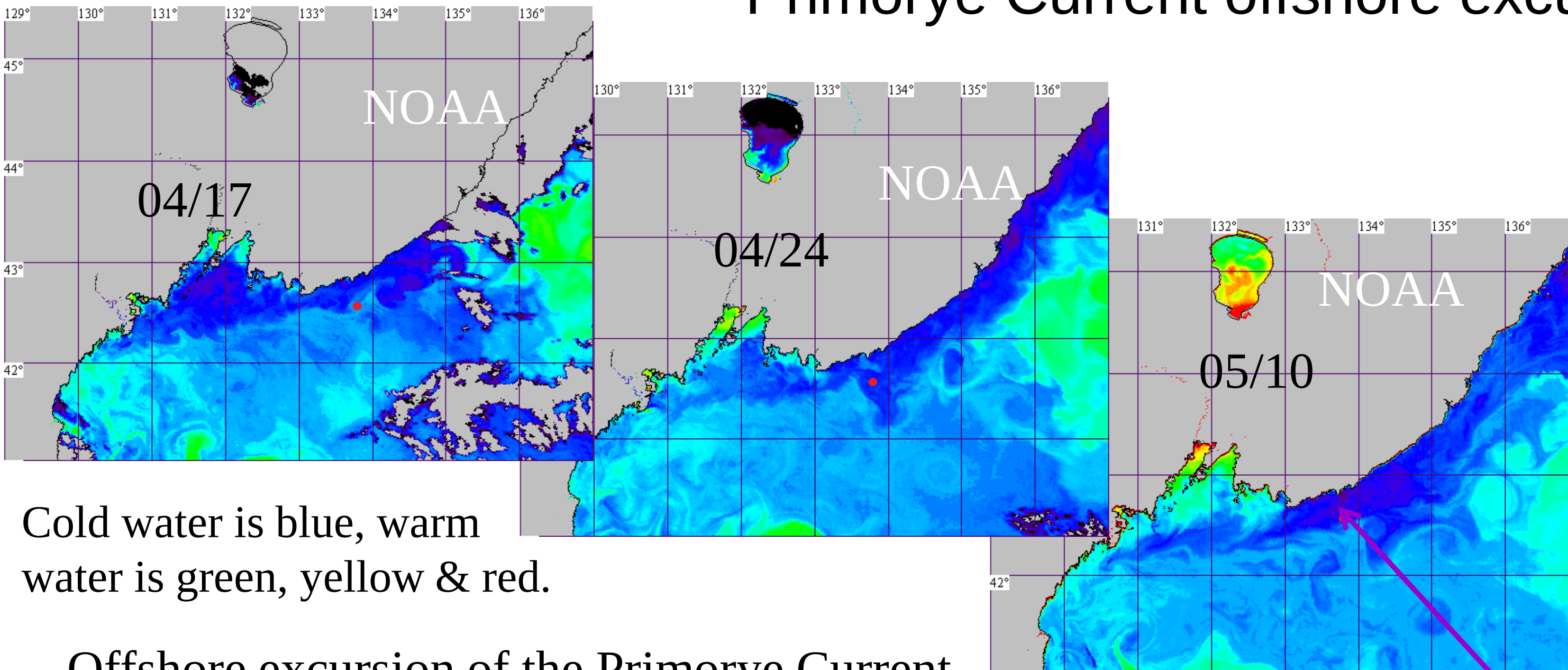




Cold water is blue, warm water is green, yellow & red.

Offshore excursion of the Primorye Current.

Primorye Current offshore excursion



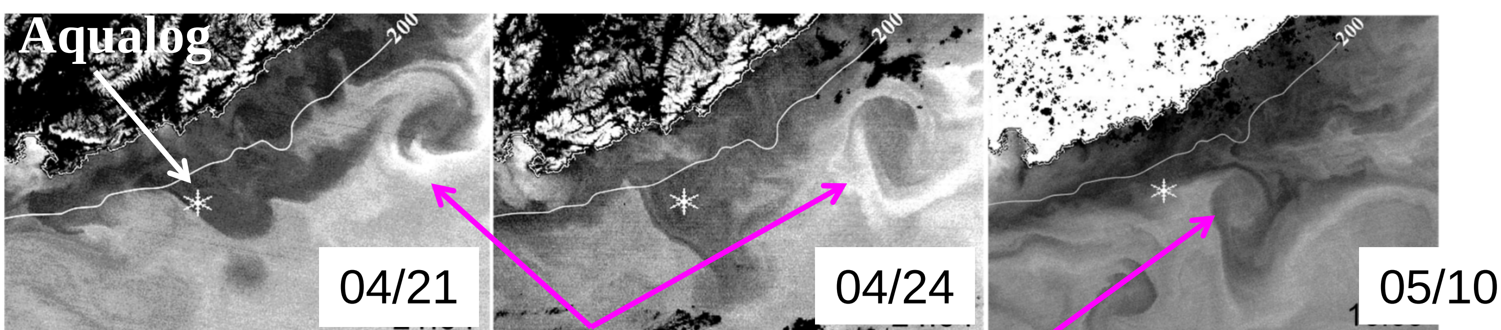
Cold water is blue, warm water is green, yellow & red.

Offshore excursion of the Primorye Current.
The front shifts first to the west, then to the east.

Aqualog location

High-resolusion from Suomi/NPP

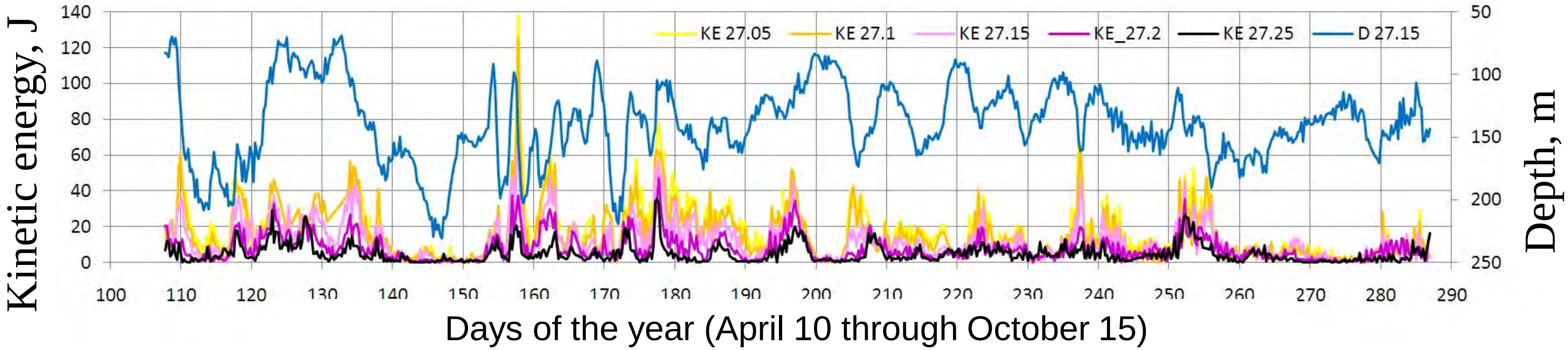
Cold water is dark, warm water is light.



Eddy moving southeastward and merging with the front.

Current intensity (kinetic energy)

Kinetic energy (D27.05 – D27.25)



σ_θ	D27.05	D27.10	D27.15	D27.20	D27.25
Median	13.6	11.6	8.5	5.8	3.2
Spread	6.3	6.4	4.4	2.6	1.8

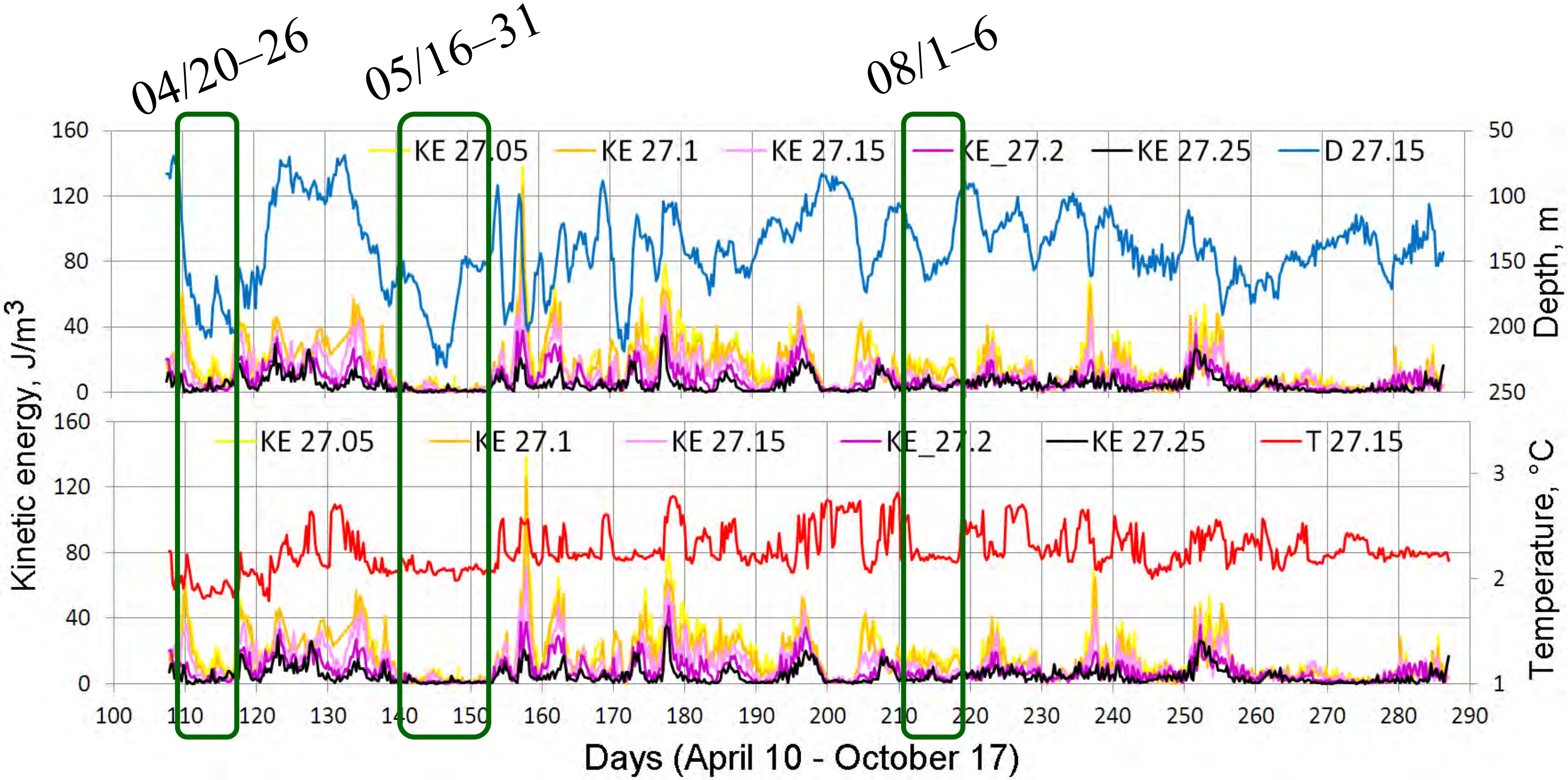
CV ~40–50%;
3.5 times decrease from D27.05 to D27.25.

Correlations (Spearman)

σ_θ	27.10	27.15	27.20
27.15	0.93		
27.20	0.84	0.90	
27.25	0.67	0.72	0.82

Coherent fluctuations in the entire profiled layer.
High-energy events of strong currents (passage of dynamic structures) and longer stagnation periods.

Events of isopycnal deepening, stagnation, and constant T



April 20 – 26: Primorye Current intrusion;
May 16–31: passage of a large eddy;
August 1–6: unclear nature (no satellite images).

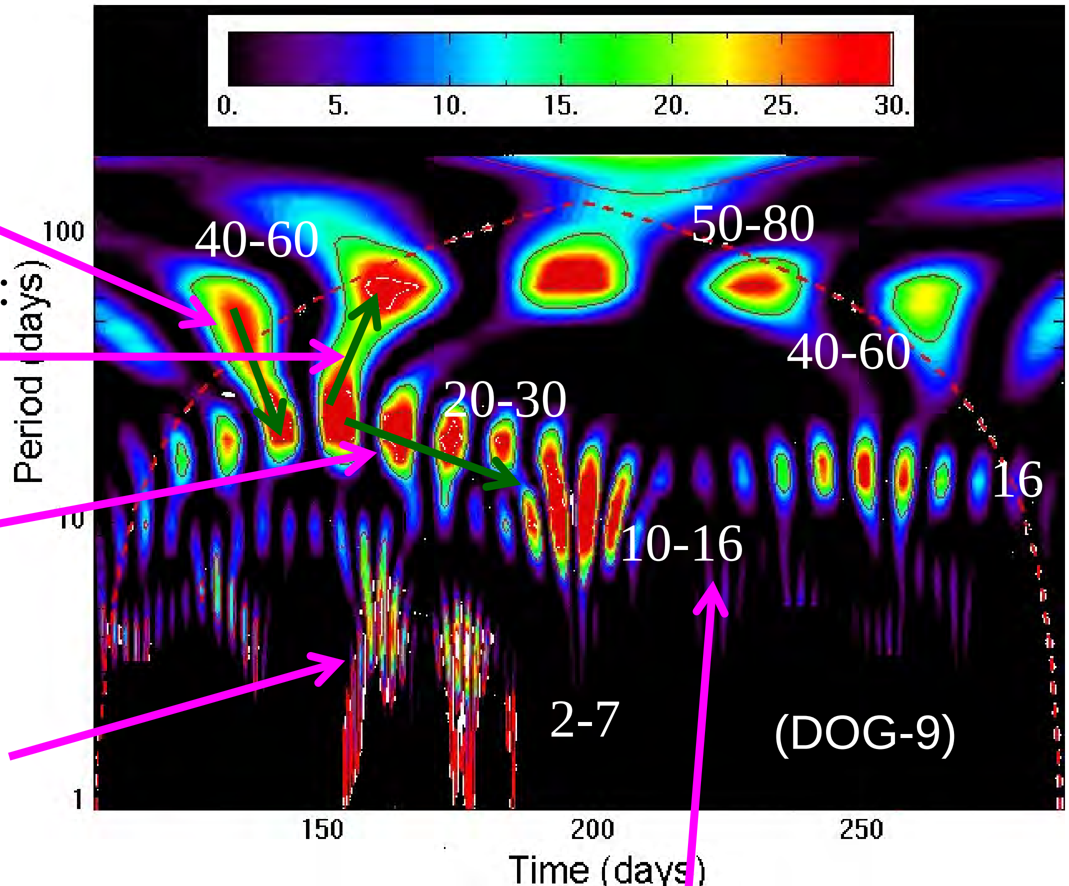
Wavelet power spectrum of KE at D27.15: non-stationarity

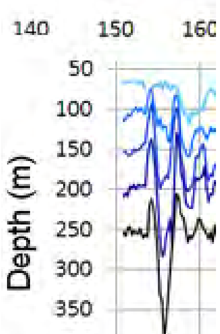
Energy cascade:
Mid through late May:
40-60 → 20-30 days

Early through mid June:
20-30 → 50-70 days

Period decrease in June – early July

Short-period variability in June, as in D





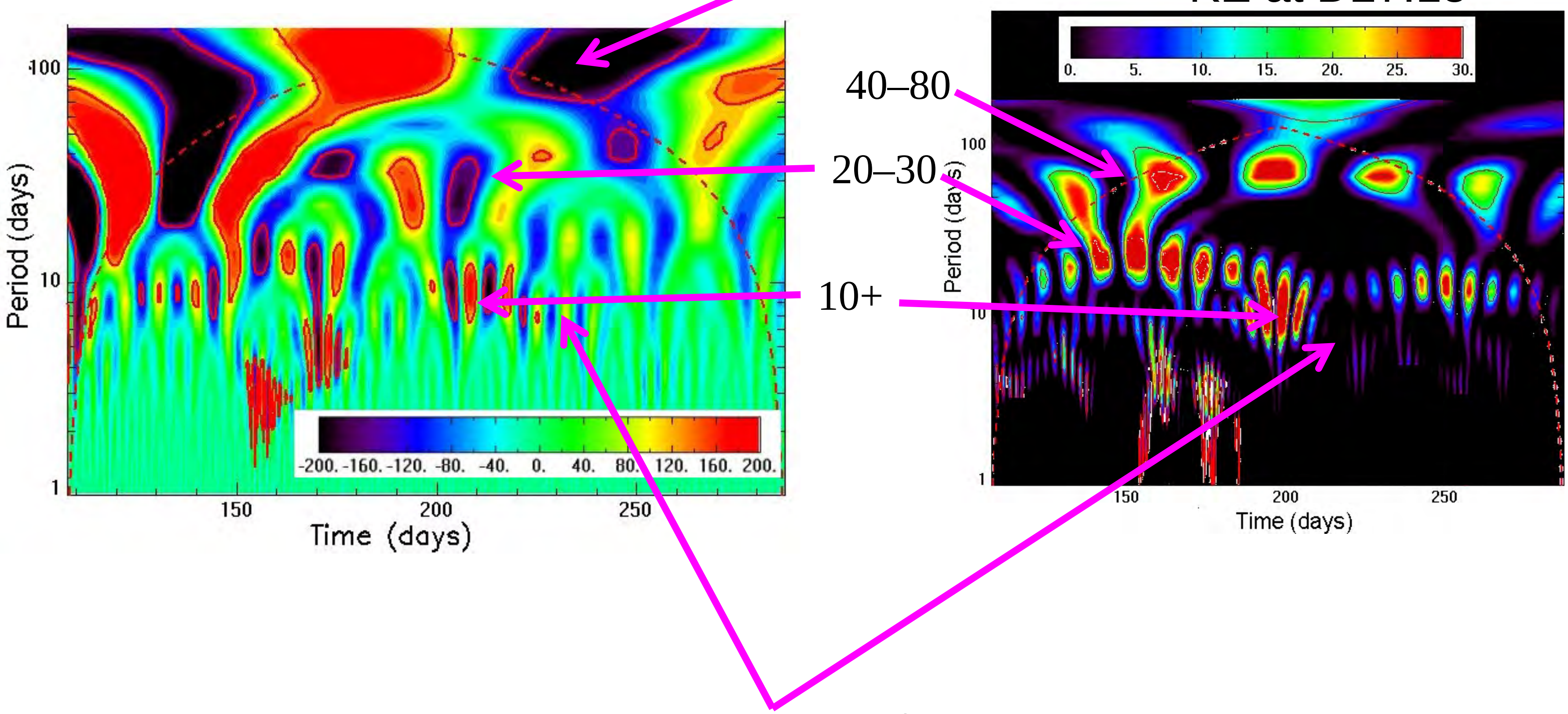
Max isopycnal drop at the edge of the large eddy

Stagnation in early August followed by weak variability

Weakening of fluctuations since mid August

WT, D27.15 depth

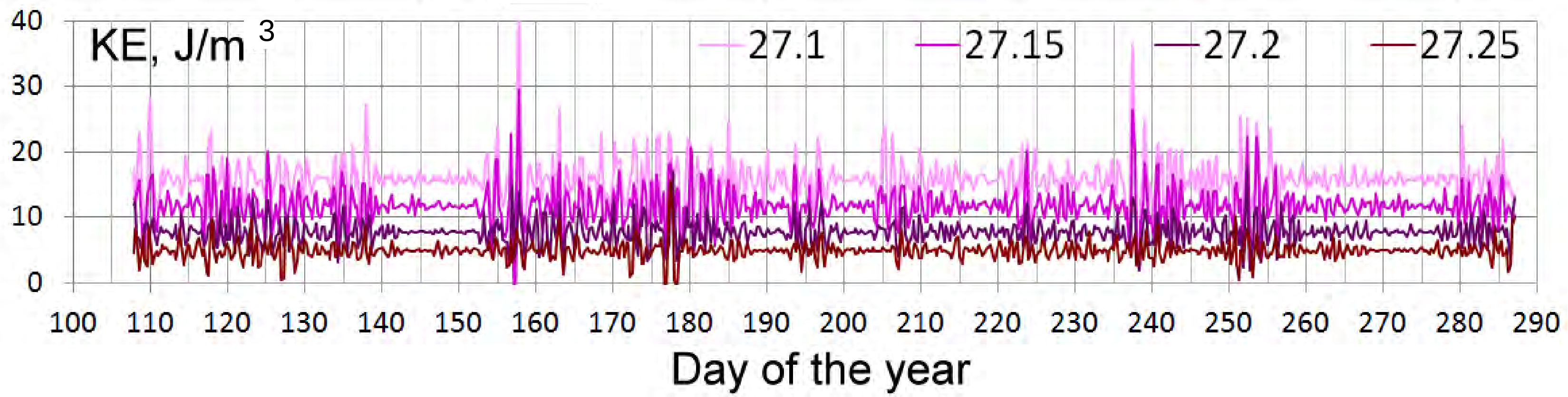
Wavelet power spectrum,
KE at D27.15



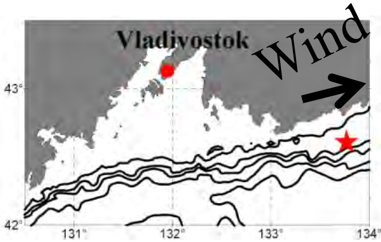
Fluctuations weaken from early/mid August,
although D & KE time scales are not quite the same
(KE more regular).

Short-term KE fluctuations

Tidal & inertial KE fluctuations (T < 1.2 days):
coherent at the D27.1 – D27.25 and highly non-stationary



Short-term KE fluctuations



Tidal & inertial KE fluctuations (T < 1.2 days):
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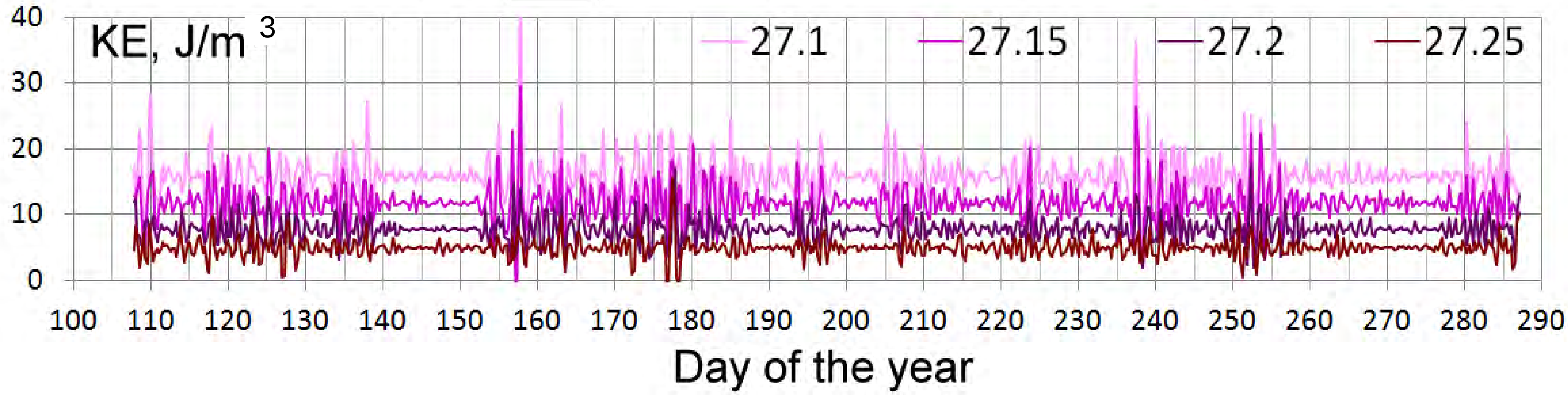
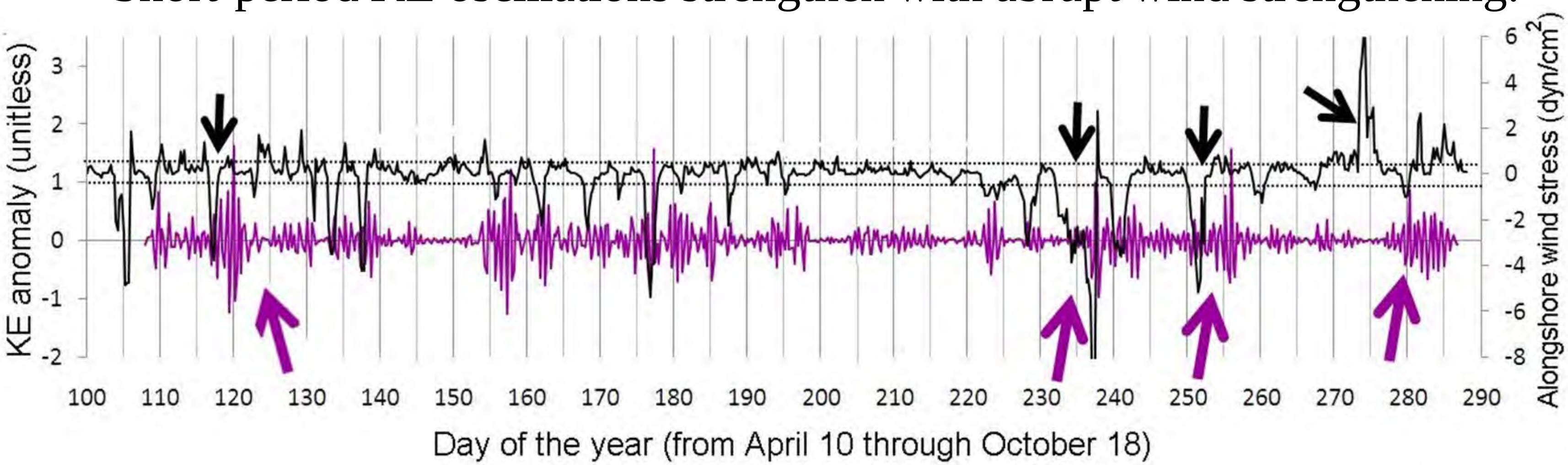


Short-period KE oscillations strengthen with abrupt wind strengthening.



KE (purple) & alongshore wind stress (black; positive for WNW wind; CFSR/NCEP).

Conclusion

- Coherent vertical fluctuations of isopycnal depths in the lower part of the profiled layer, while weak fluctuations in the upper part: the signal does not come from the surface, probably advected;
  time scales: 100+, 20–30, <20, <10 days, non-stationarity.
- Coherent fluctuations of temperature at the isopycnals in the upper part of the profiled layer: alien water intrusions at the edges of large structures;
  time scales: 100+, 25–30, 7–10 days, non-stationarity.
- High-energy events of strong currents, coherent in the entire profiled layer and longer stagnation periods; time scales: 50–80, 20–30, 10–20, 2–7 days and < 1 day.
- **D & KE fluctuations weakened since mid August.**
- Strengthening of short-period (inertial) KE fluctuations after the passage of atmospheric disturbances.