Recent Trends and Future Perspectives of Upwelling Events in the Gulf of Trieste

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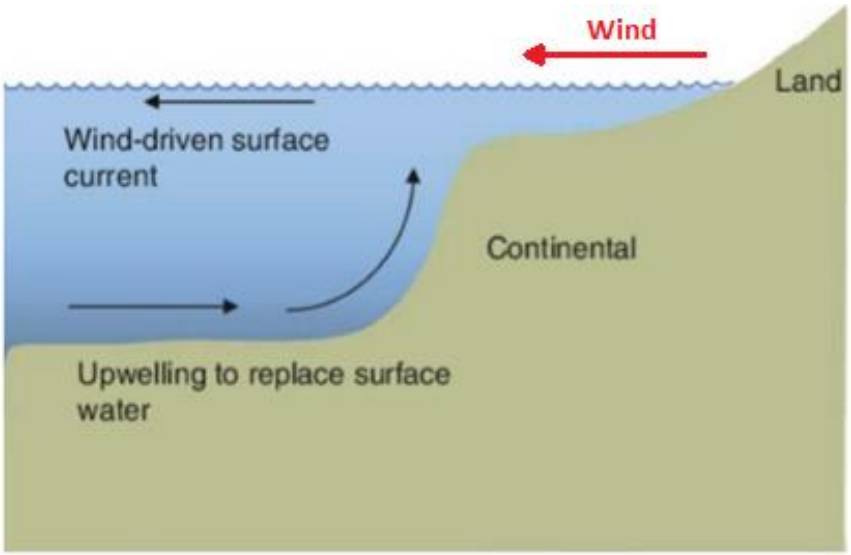
Outline

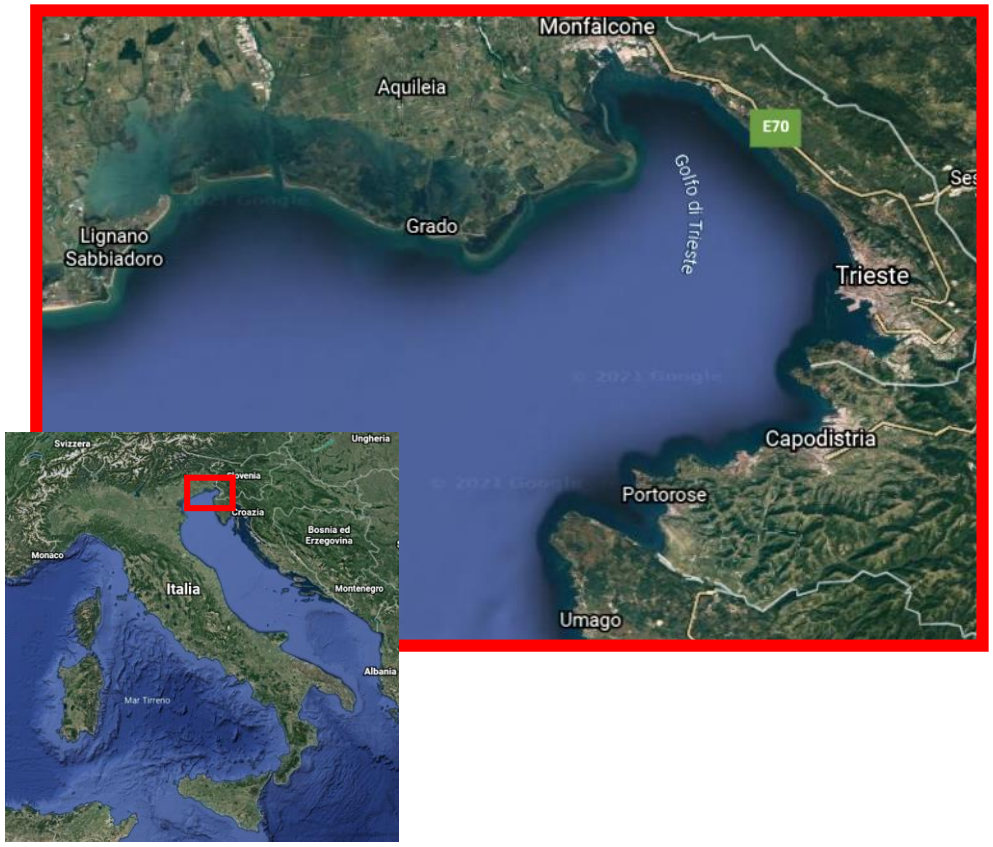
- **Coastal Upwelling** in the **Gulf of Trieste**
- **Aim** of the Study
- **Methods** & **Analysis**
- **Conclusions** & **Perspectives**

Coastal Upwelling



- **Upward movement** of **seawater** parcels, rising by continuity near the **coast**, from bottom to surface, to replenish water masses moved offshore by the **wind** action
- Strong **impact** on the **biogeochemical** processes and **phytoplankton** development (**rising** of **nutrients**)
- It allows the **ventilation** of the **bottom layers**
- In the **Gulf of Trieste**, Earth **rotation effects** are **negligible**: the offshore transport of water masses is due to **winds transversal** to the coast
- In the **Gulf of Trieste**, coastal **upwelling** occurs almost **adiabatically,** due to intense **Bora** wind (ENE) episodes

The Gulf of Trieste



- **Small** (21 km × 29 km), **shallow** (max. depth 25 m) and **semi-enclosed** basin at the **northernmost** part of the **Adriatic Sea**
- It has a **remarkable** seasonal **variability** in its ocean properties, and hence in its circulation
- Its **freshwater input** comes mostly from the **Isonzo** and **Timavo** rivers
- Several **winds** blow on it: **land** and **sea breezes**, **Scirocco** (SE) and **Bora** (ENE)

Aim of the Study

- Assuming that one of the effects of the ongoing **climate change** is the **strengthening** of the **thermocline** in the **Gulf of Trieste**, the amount of work required to mix the water column may be increased, and hence the number of **coastal upwelling** episodes may be **decreased**

- The **aim** of this study is to **investigate trends** in the evolution of **coastal upwelling** episodes, occurred in the **Gulf of Trieste** during the **summer** (April-September) and **winter** (October-March) **semesters** of the **last two decades** (2000-2019)

Methods of the Study

- **Linking** of atmospheric **synoptic** conditions to **local** (micro-scale) meteo-marine effects
- Use of **modeling** to **estimate** the effective **mixing** characteristic **time** of the **water column** in the **Gulf of Trieste**
- Use of **synoptic** scale conditions as **proxy** for **local** scale **trends**

Atmospheric & Oceanographic Data

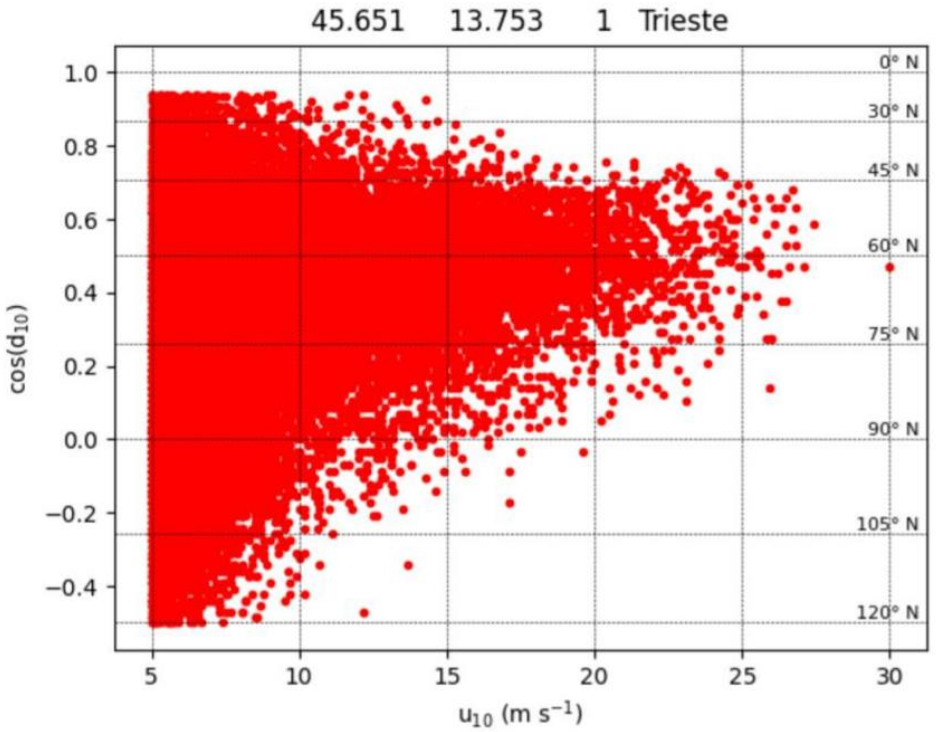
Atmospheric Data	
CRMA (ARPA FVG)	• **wind direction** and **speed** • **hourly** resolution • **8** weather **stations** over **Friuli-Venezia Giulia**'s land and sea • 2000/01/01 - 2019/11/30
ECMWF	• **mean sea level pressure** • **six-hour** resolution • **50 km × 50 km** over the whole **European continent** • 1980/01/01 - 2019/12/31

Oceanographic Data	
CRMA (ARPA FVG)	• **sea surface** (0.5 m of depth) **temperature** • **hourly** resolution • **Trieste** (F.lli Bandiera pier) • 2000/01/01 - 2019/12/31
OGS	• **sea temperature** at **two depths** (2 m and 11.5 m) • **three-hour** resolution • **S. Croce** • 2017/01/01 - 2017/12/31

Detection and Features of Bora Wind Episodes: Meteorological Micro-Scale

Bora wind **episodes** have been **detected** at the meteorological **micro-scale** (CRMA-ARPA FVG data) by filtering those recordings characterized by a **wind direction** d_{10} and a **wind speed** u_{10} included in the following domains of existence:

- $20° \text{ N} \leq d_{10} \leq 120° \text{ N}$
- $u_{10} \geq 5 \text{ m s}^{-1}$



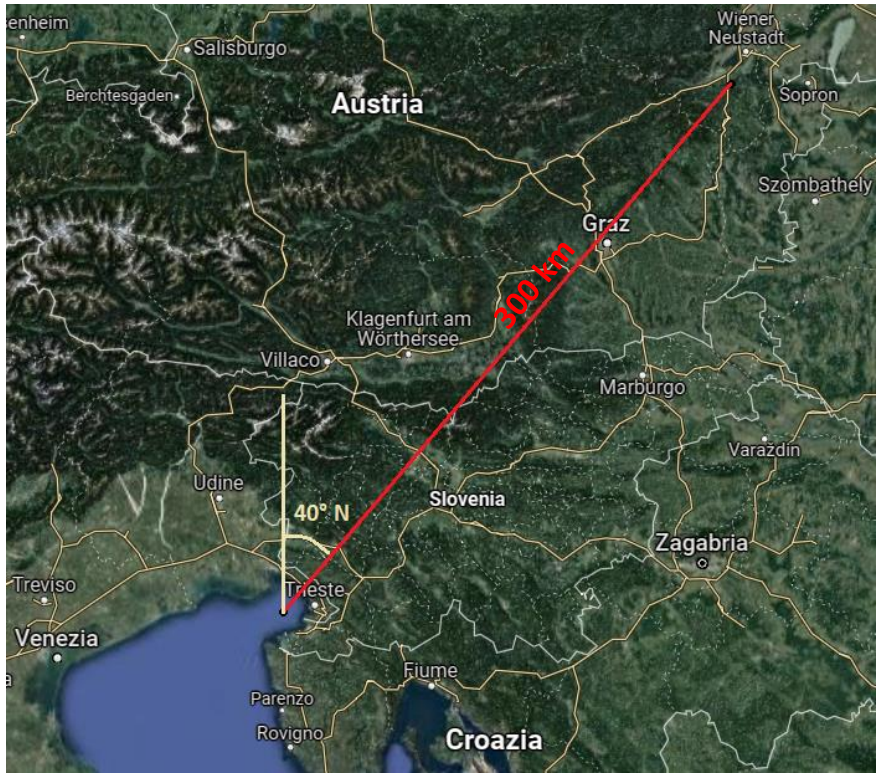
Linking of Synoptic Scale Conditions to Local Bora Wind Episodes

- **Bora** wind has a **synoptic** origin and it is determined by the **geostrophic balance** ($\vec{\nabla}p \sim \vec{F}_{Coriolis}$):

$$\vec{u}_g = \frac{1}{\rho f}\hat{k} \times \vec{\nabla}p$$

- **Linking** of **synoptic** scale conditions to **local** scale effects has been performed by the use of the **mean seal level pressure gradient**, computed between the **center** of the **Gulf of Trieste** (identified as the P.A.L.O.M.A buoy, 45.6182° N, 13.5653° E) and a set of **continental points**, **300 km** far from P.A.L.O.M.A and **equally distributed** (1°) around it (from 20 °N to 120° N)

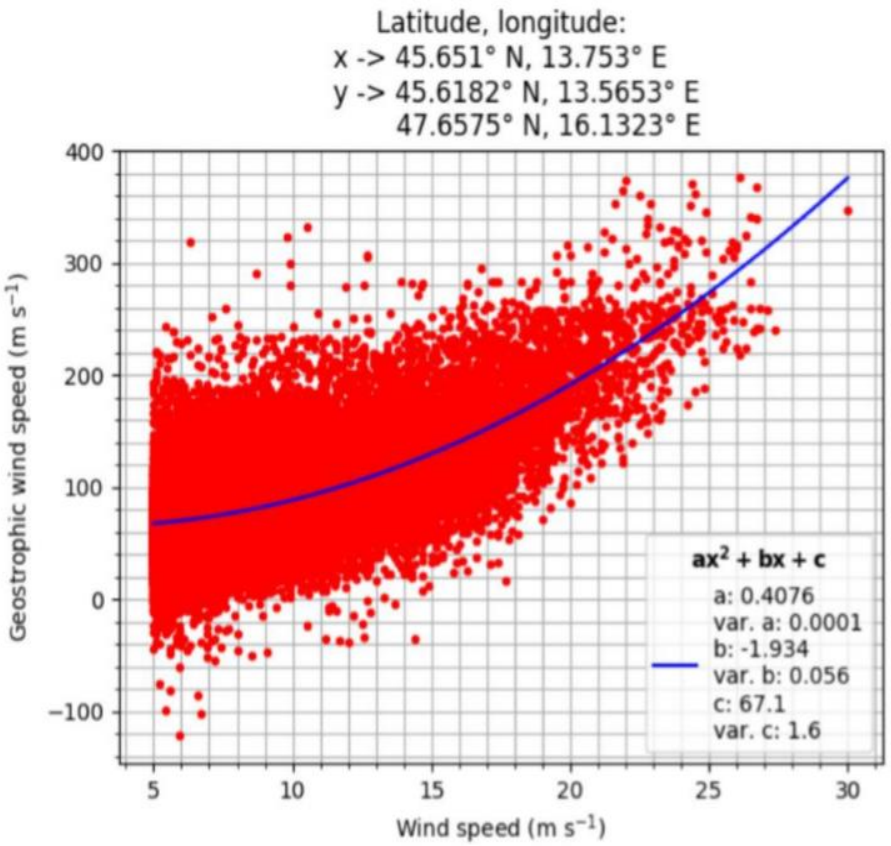
Best-fit of Pressure Gradient with Local Bora Wind



A **linear regression** analysis has been performed on the **wind speed** measured at the **local** scale (Trieste), **during Bora** wind episodes, and the **geostrophic wind speed** (**synoptic** scale) computed for **each** explored **direction**, in order to find that exhibiting the **highest correlation**:

- bearing: 40° N
- PCC: 0.623
- p-value: ≈0

Local and Geostrophic Wind: Best-fit Function



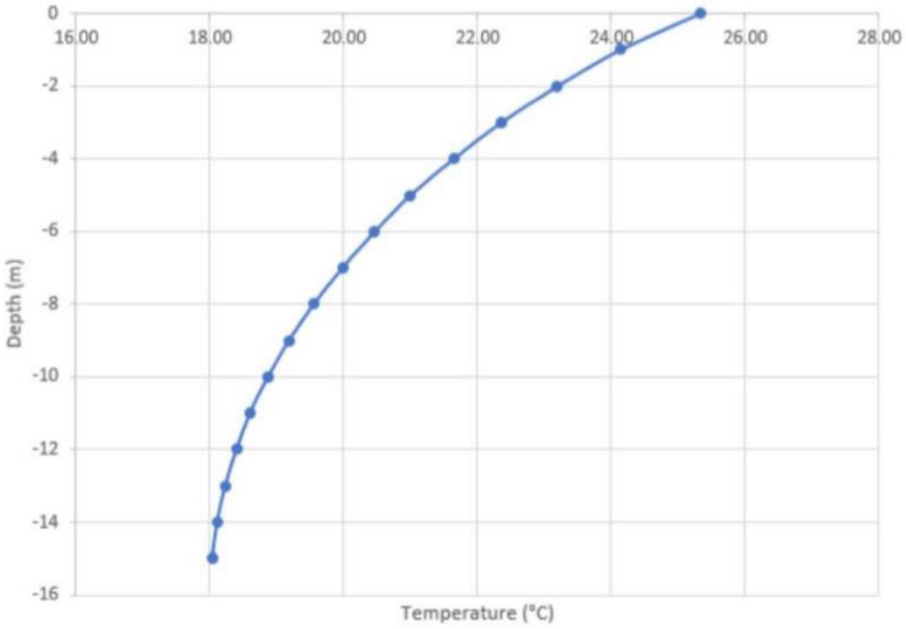
Best-fit between **geostrophic** wind speed, computed along the **direction** of **highest correlation**, and **local** (micro-scale) **Bora** wind speed, measured in **Trieste**

Empirical **function downscaling synoptic** conditions into **micro-scale** effects: it takes into account for **local** atmospheric **boundary layer effects** (e.g. drag, turbulence, orography) in the description of the **synoptic Bora** wind

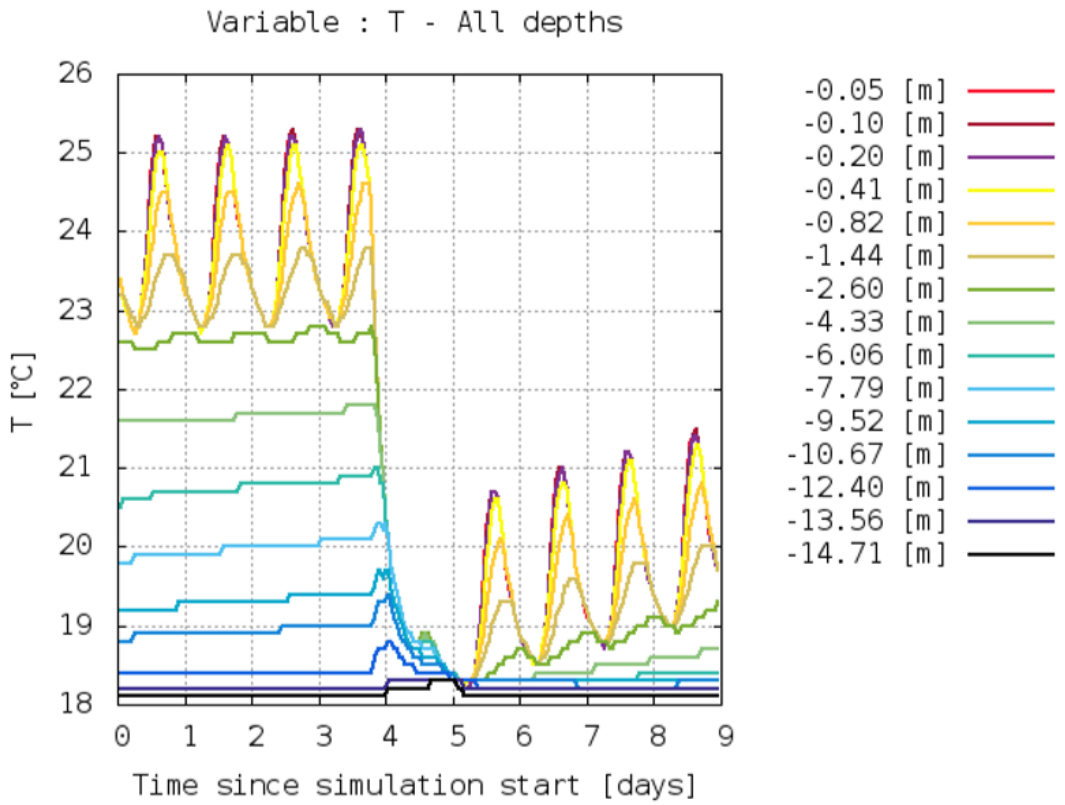
Estimation of the Effective Mixing Characteristic Time with Numerical Modeling

Features of the Modeling Analysis	
Model	**POM** (Princeton Ocean Model) **1D**
Aim	**Reproduce** coastal **upwelling** under the action of a **strong**, summer **Bora** wind episode, to **estimate** the **effective mixing** characteristic **time** of the whole **water column** in the **Gulf of Trieste**
Methods	**Two simulations**: • both forced by the **same** strong **Bora** wind episode, preceded and followed by summer, sunny days (WRF model, 2 km × 2 km) • initialized with **different** thermohaline, **vertical profiles** (**weaker** and **stronger thermocline**)

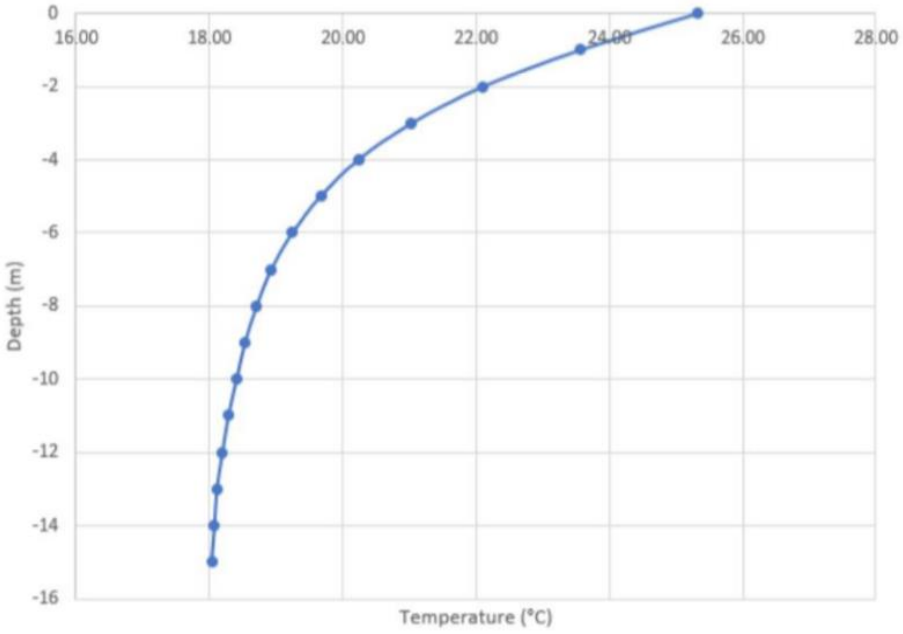
Weaker Thermocline



	Time
Effective mixing	~12 hours
Homogenization	~24 hours
Thermocline restoration	~hours



Stronger Thermocline



	Time
Effective mixing	~12 hours
Homogenization	~24 hours
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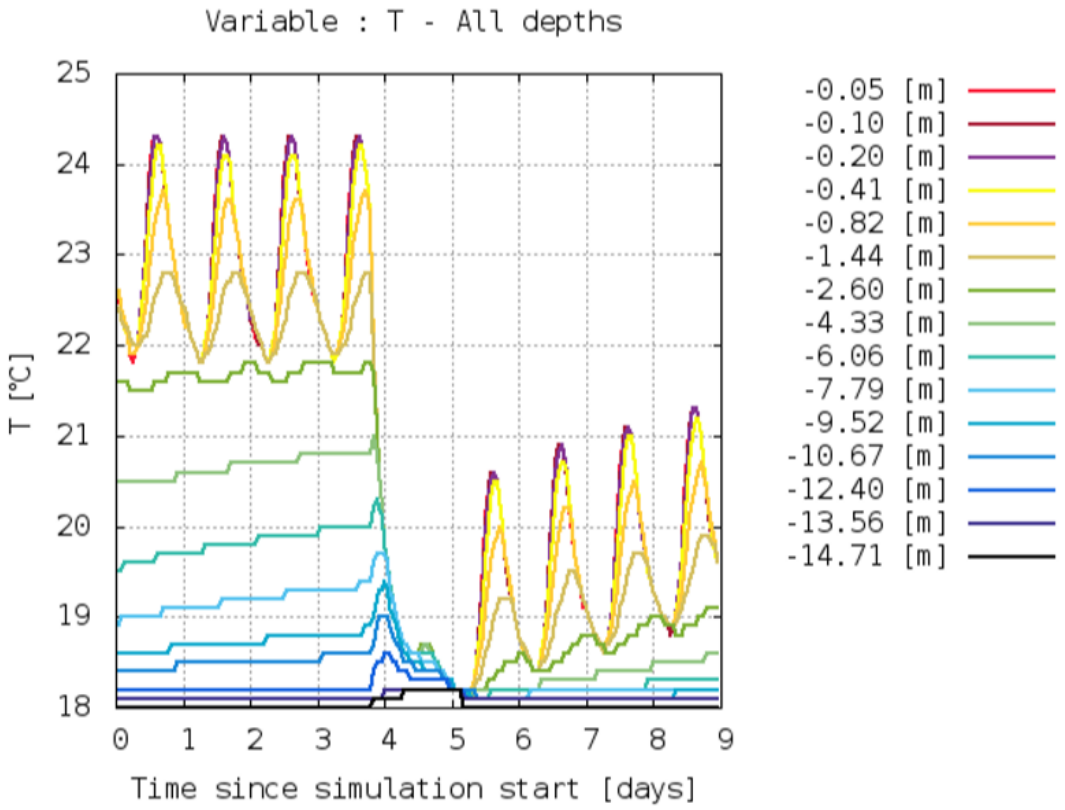


Measured vs. Estimated Bora Wind Episodes: Any Trend?

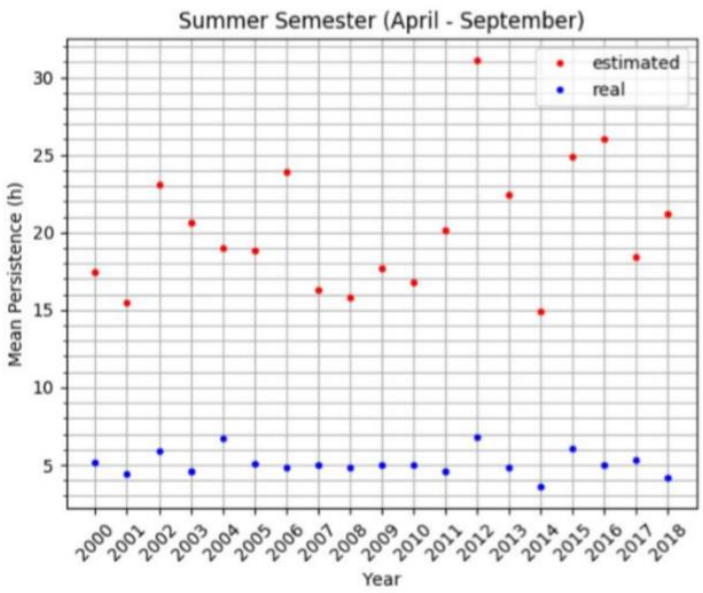
- **Measured** = **Local**
- **Estimated** = **Synoptic**

- **Persistence** in **hours**:

Time	Bora?	Pers. (h)
… 11:00	… no	-
12:00 13:00	yes yes	2
14:00 …	no …	-

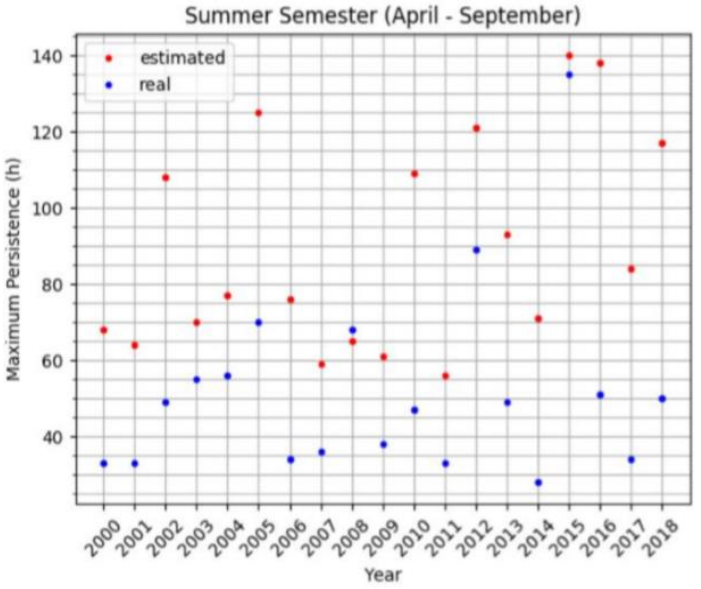
- **19-years** analysis (2000-2018)
- **summer** semesters (April-September)

Important for upwelling



	P-value	
Local	> 0.05	**no trends**
Synoptic	> 0.05	**no trends**

Very important for upwelling



	P-value	
Local	> 0.05	**no trends**
Synoptic	> 0.05	**no trends**

Conclusions & Perspectives

- In the **Gulf of Trieste**, coastal **upwelling** events are **strictly related** to **Bora** wind episodes
- Summer **Bora** wind episodes **lasting** more than about **12 hours** effectively **mix** the whole **water column**
- It is possible to use the **mean sea level pressure gradient** at the **synoptic** scale as **proxy** for the identification of **Bora** wind episodes at the **local** scale (some biases have to be taken into account)
- There are **no trends** in coastal **upwelling** episodes in the **last 19 years** (**same results** for both **summer** and **winter**)
- **Downscaling** of **mean sea level pressure gradient** can be used for **climatic projections** of future trends in **coastal upwelling** episodes (**EURO-CORDEX** data, **AdriaClim** project)

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