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Sea/land breeze (SLB) along the north-eastern Adriatic coast

Pure SLB, SLB & bora, SLB &air quality, SLB & Cb

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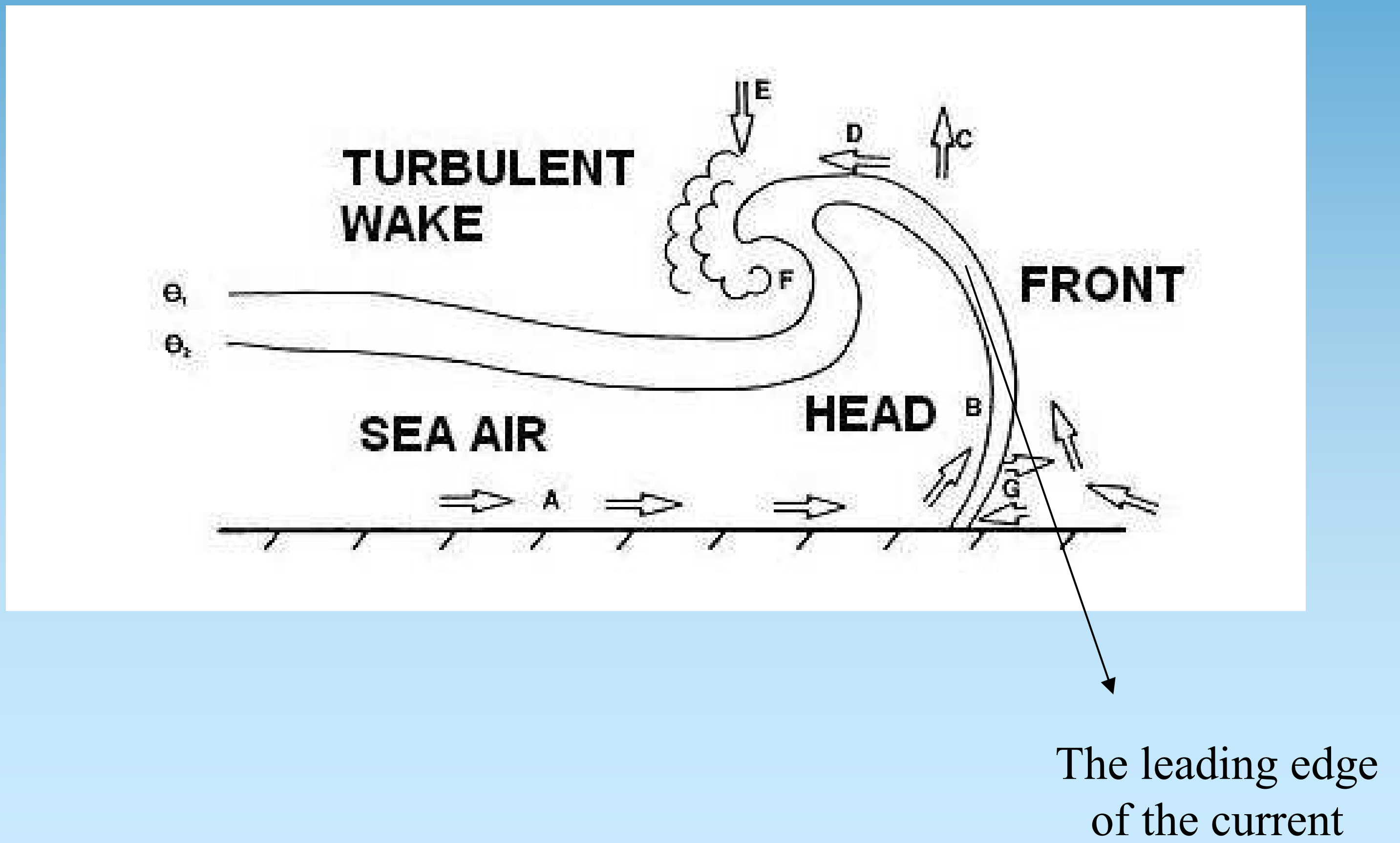
2-D schematic of a gravity current/sea breeze (from Holland and McBride, 1989)

The sea/land-breeze is a main feature of surface inhomogeneities studied very extensively for many years (e.g. Simpson 1994; Miller *et al.* 2003).



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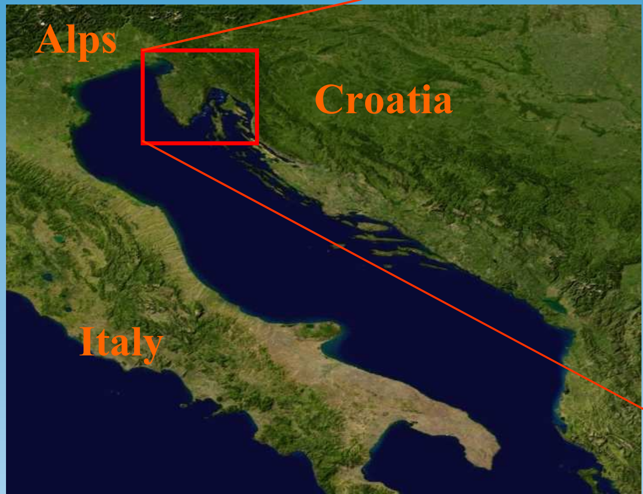
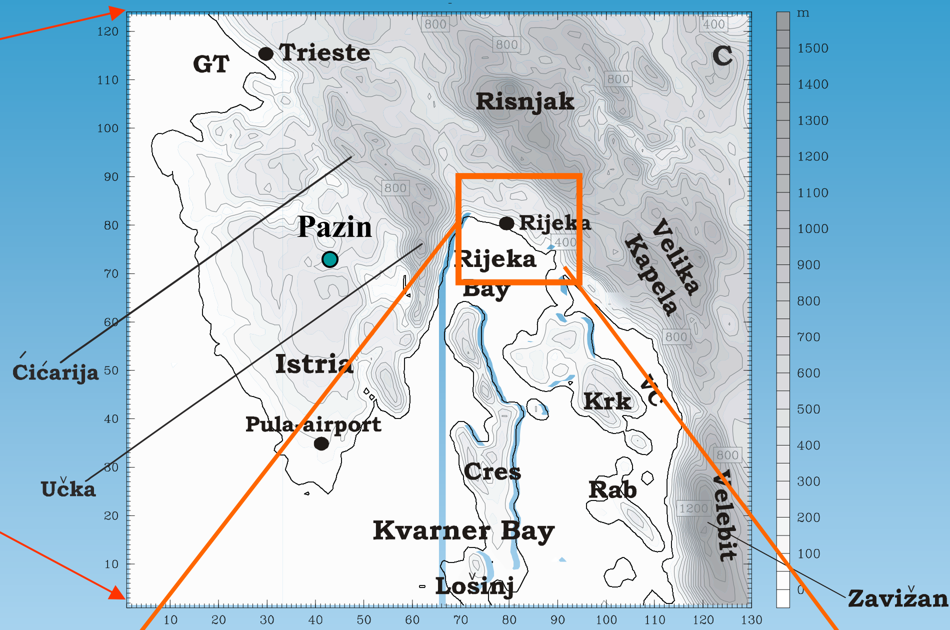
Geographic characteristics





Greater Rijeka area

- continous **ozone** monitoring started in the city of Rijeka in 1999.

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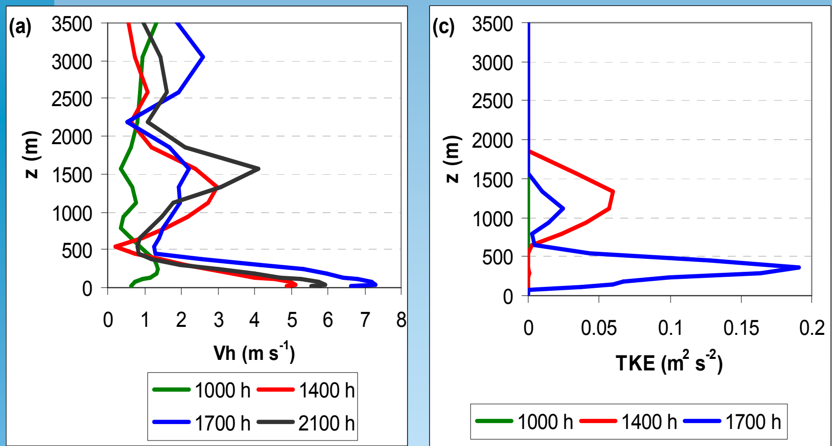
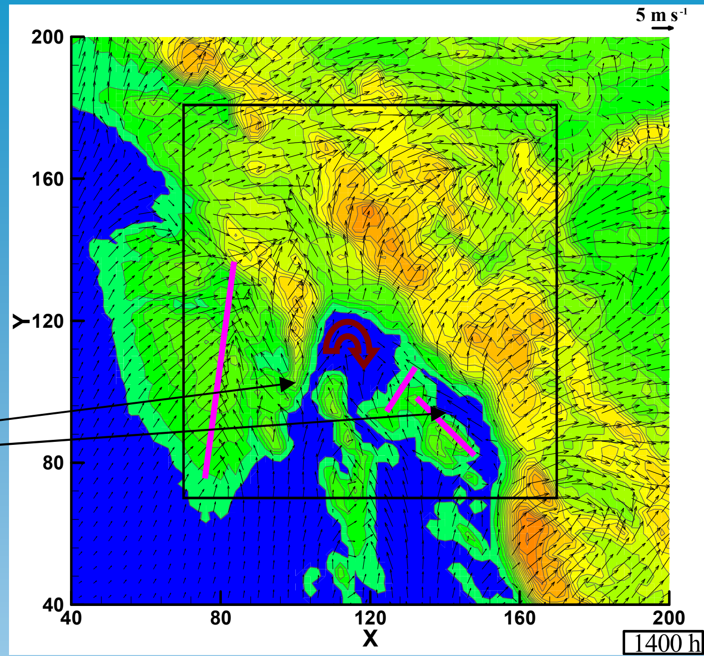
What we know about pure SLB?

During **daytime**:

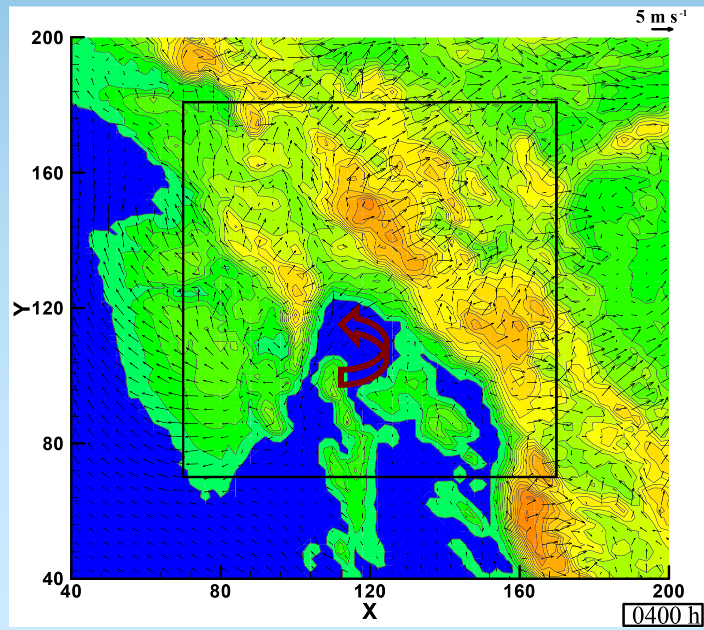
➢convergence zones
(above Istria and island of Krk)
➢afternoon anticyclonic vortex inside Rijeka Bay due to developed SB and upslope flow.
➢ coastal-jet like flows (Velebit Channel and Grate Gate)





During **nighttime**:

➢ night-time cyclonic eddy in the Rijeka Bay developed due to land breeze and katabatic flow from the surrounding mountains



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SLB development under considerable synoptic forcing e.g., during bora events

Why bora ('bura' in Croatian)?

Bora is:

1) a strong, dry and cold downslope mainly north-easterly wind; in general, opposite wind to SB

Bora wind in Senj

2) During the summer along the north-eastern Adriatic: mostly weak to moderate bora events (up to 20% of all summer days) exchange with the SB days (up to 60% of all summer days).

3) Grisogono and Belušić (2009) suggested (among others) more extensive analyses of:
weak to moderate bora flows (more frequent during summer months)
the role of the lee-side islands (e.g., islands within Kvarner Bay) during bora and

4) Air quality issues can also be highly associated with the boundary-layer structure. (e.g. observed very high ozone levels southern France during a combined summer SB/mistral event (Bastin et al. 2006) .

Sea/land breeze & bora interplay

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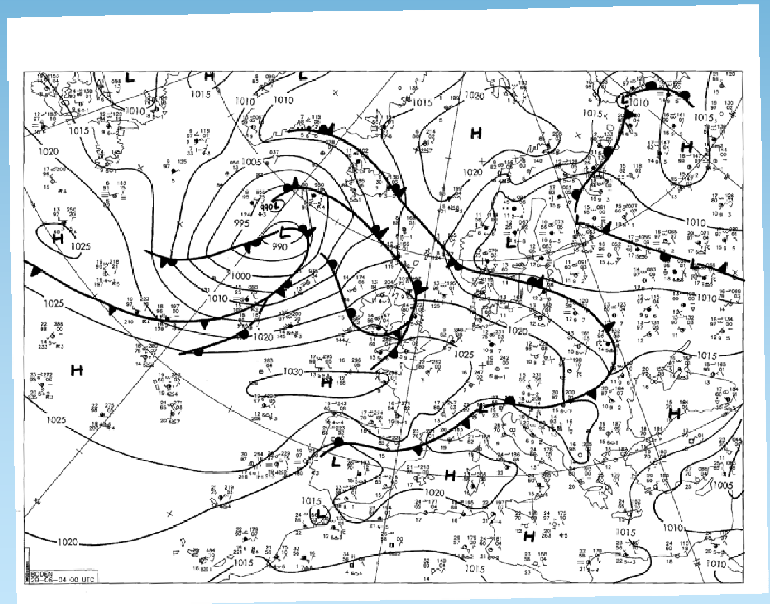
- chosen a 'frontal' bora event during 28-30 June 2004
- the bora: started at 2200 UTC on 28 June;
  : lasted 30 continuous hours;
  : reached its maximum at 1100 UTC on 29 June 2004;
  : stopped on 30 June, during early morning hours.



Surface diagnostic chart at 0000 UTC on 29 June 2004 for Europe.

Does SLB exist during a summer bora event and where?

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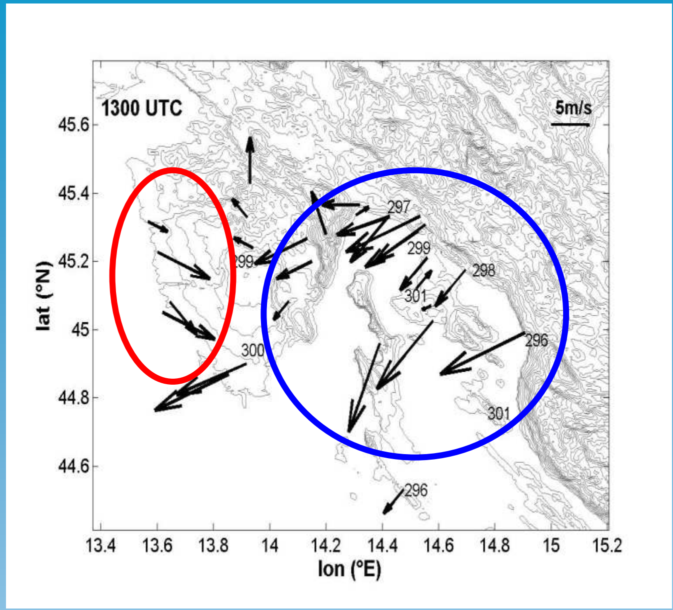
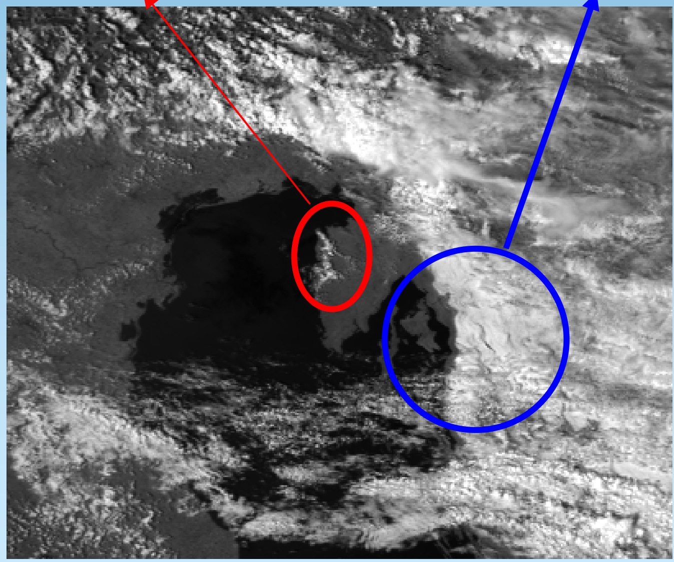
Near surface wind on 29 June 2004



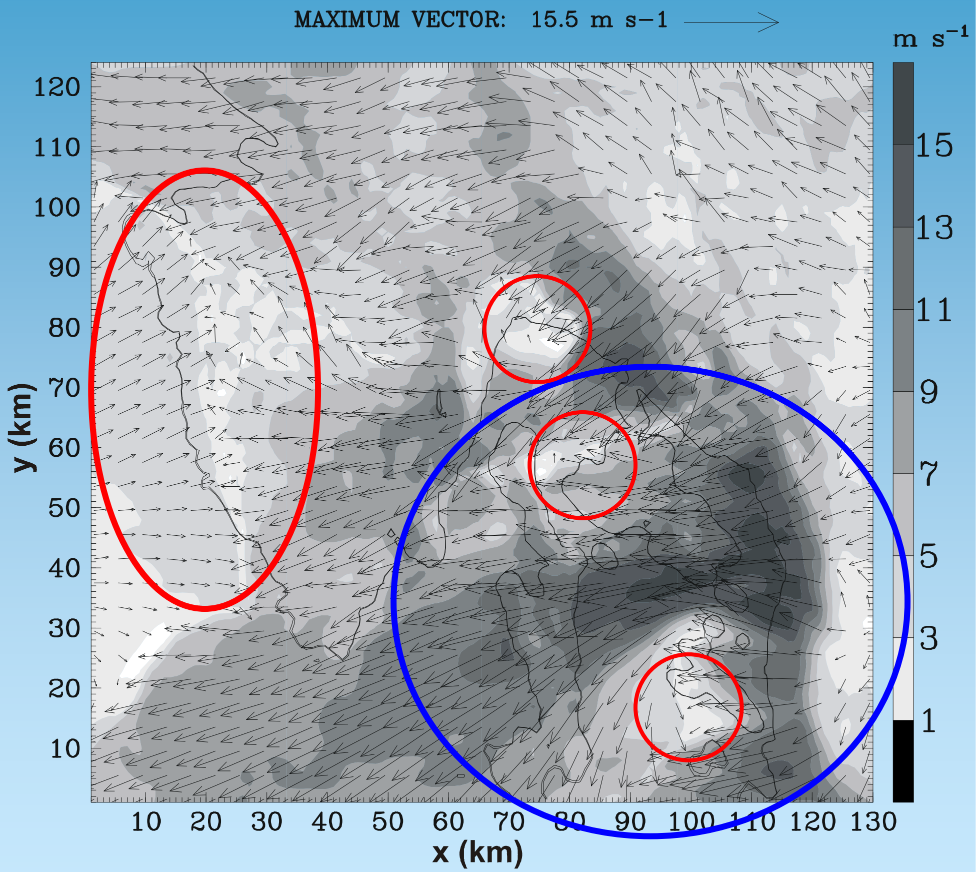
Measured surface wind field

sea breeze

bora



Satelite image NOAA16, 12:38 LT



WRF 1-km surface wind field (10 m) at 1300 UTC

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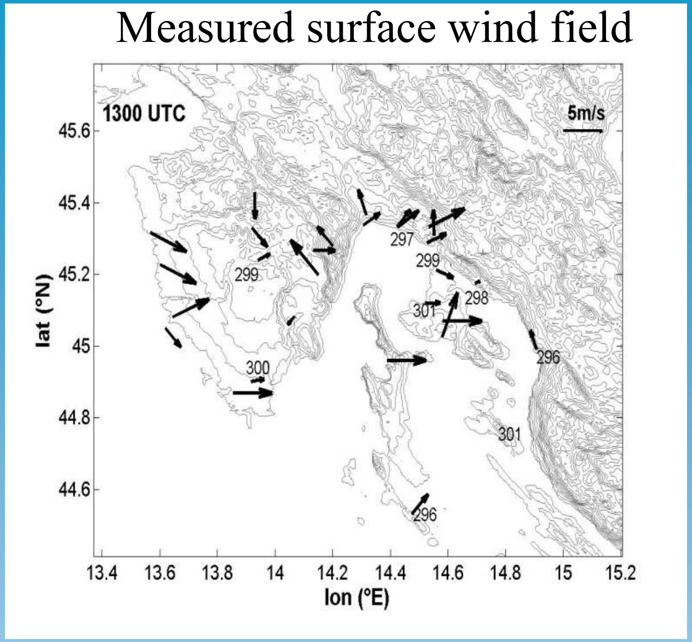
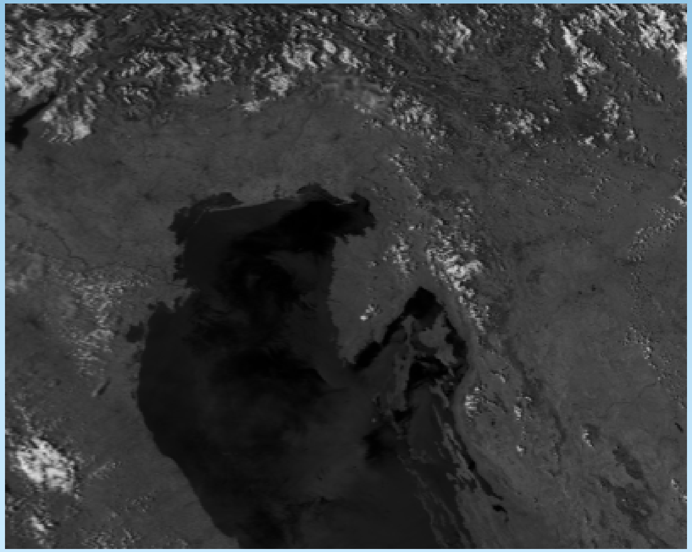
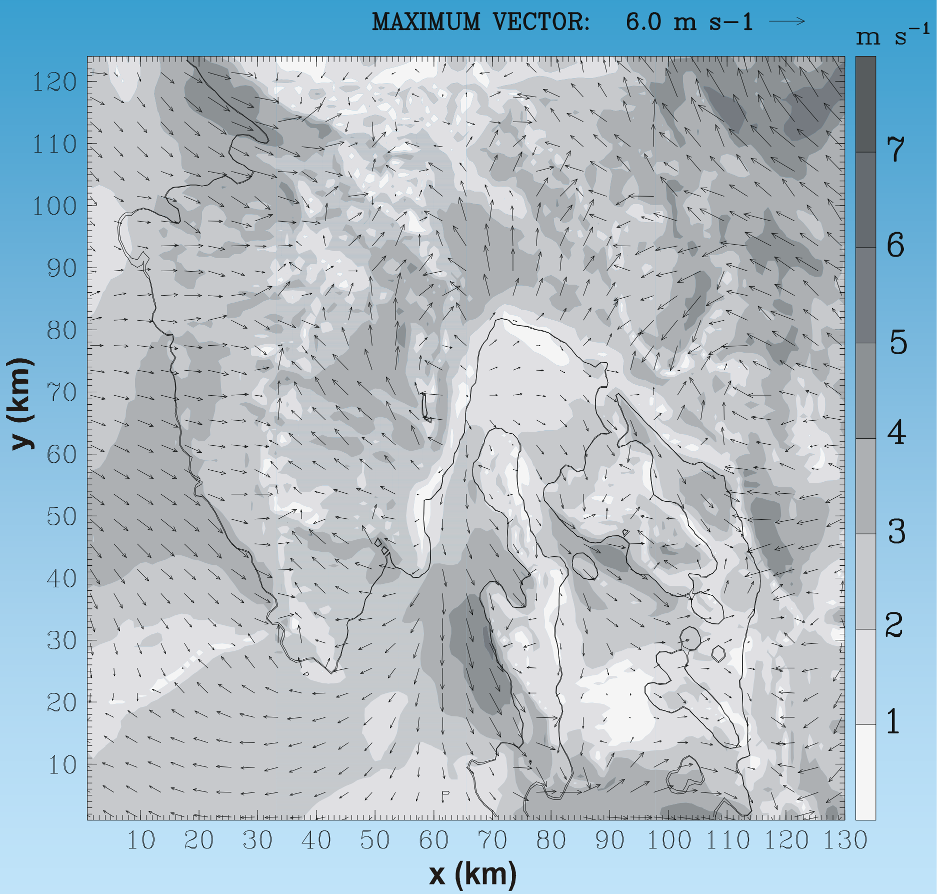
Near surface wind on 30 June 2004





Satelite image NOAA16, 12:27 UTC



WRF 1-km surface wind field (10 m) at 1300 UTC

SB & bora interplay

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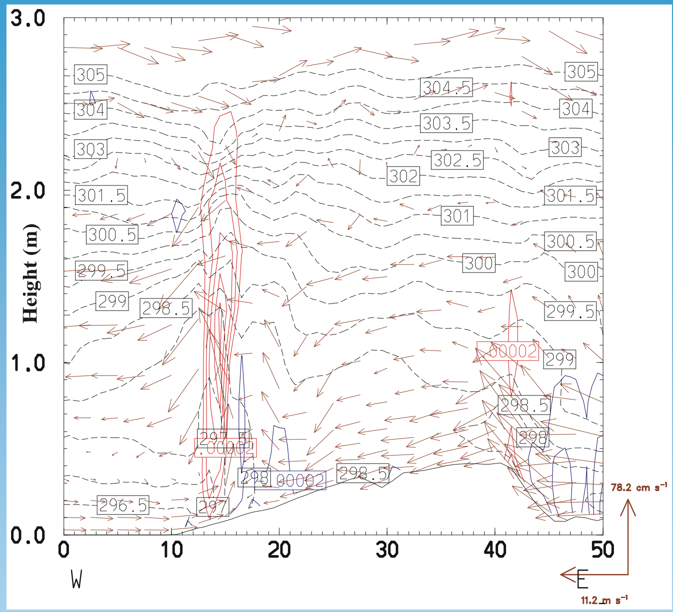
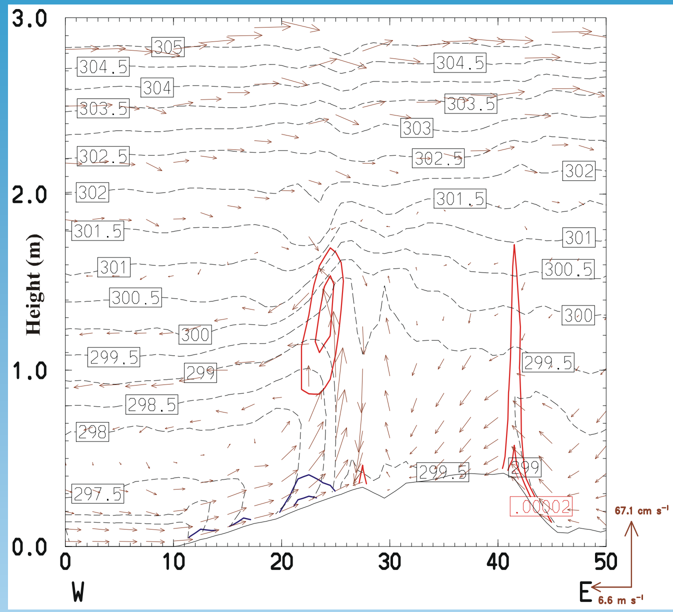
29 June 2004 at 1300 UTC



30 June 2004 at 1300 UTC



Vertical cross-sections of the modelled wind (m s-1), the potential temperature (K) and horizontal pressure gradient (hPa m-1)

SB during summer bora was

- later and shorter
- limited horizontal (and sometimes vertical) extent
- e.g. inland penetration 6 km versus 16 km
  - SB depth 400 m versus 600 m
- stronger SB intensity.

Sea/land breeze & bora interplay

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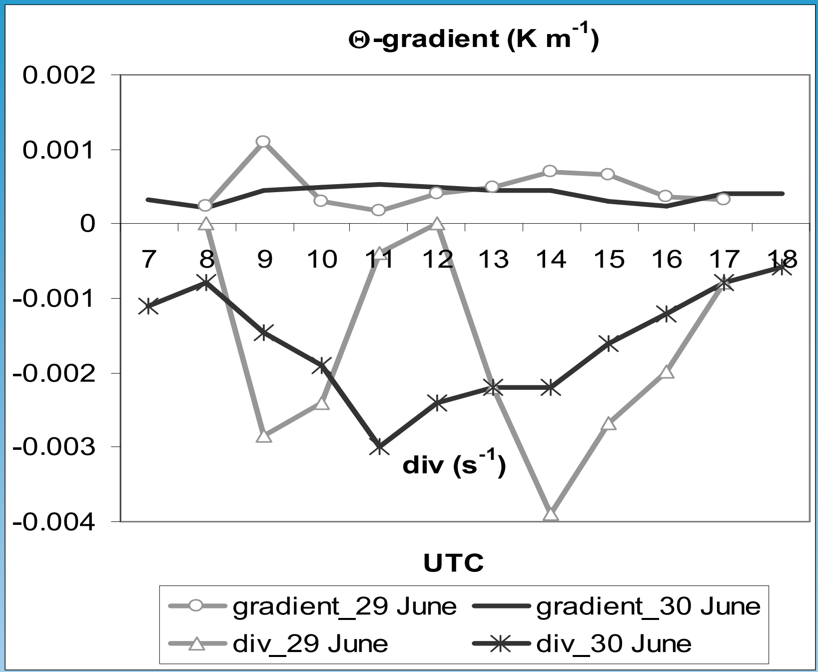

Changes with time during 29 June 2004 (gray) and 30 June 2004 (black) of the potential temperature gradient (K m^{-1}) and divergence (s^{-1}) across the sea breeze front along vertical cross-section.

1) **0800 UTC-1200 UTC;**
the onshore flow represents the superposition of the dominant swirled bora flow north of Istria and a very weak SB wind onshore flow

2) **1200 UTC-1700 UTC**; the reduced bora intensity:
decreased the width of the SB front $\Rightarrow$ increased temperature gradients across it

α =the orientation of the gravity current head in respect to the x-axis

α (SB/bora) versus α (pure SB) ~ 45°/11°

$\nabla_H p$ (SB/bora) $\approx 2\, \nabla_H p$ (pure SB)

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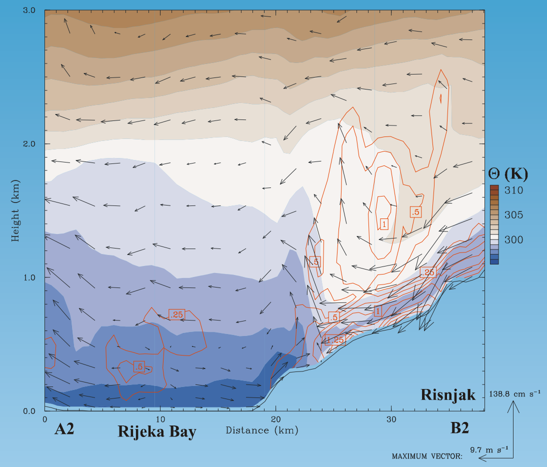
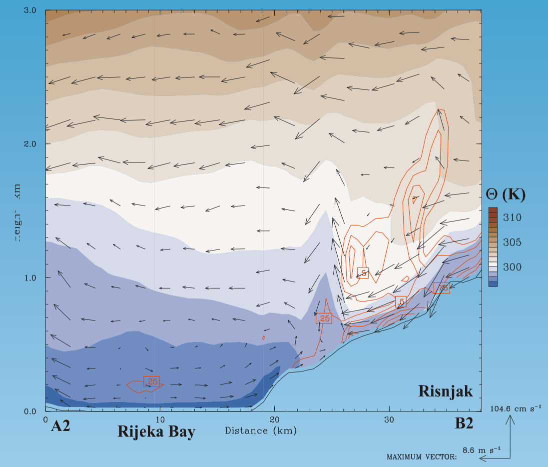
Cross-section near Opatija of the modelled wind (m s^{-1}), the potential temperature (K) and TKE (m^2s^{-2})

29 June 2004

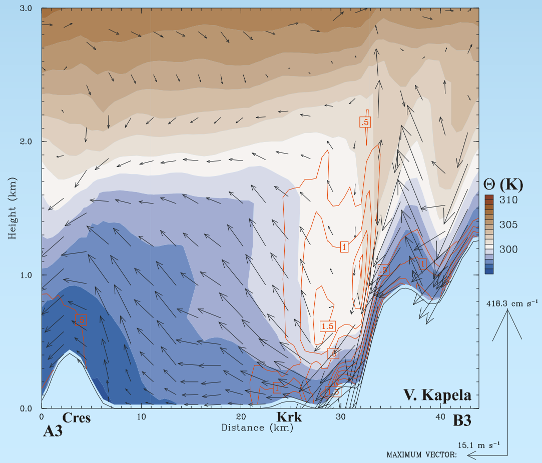
14:00 LT

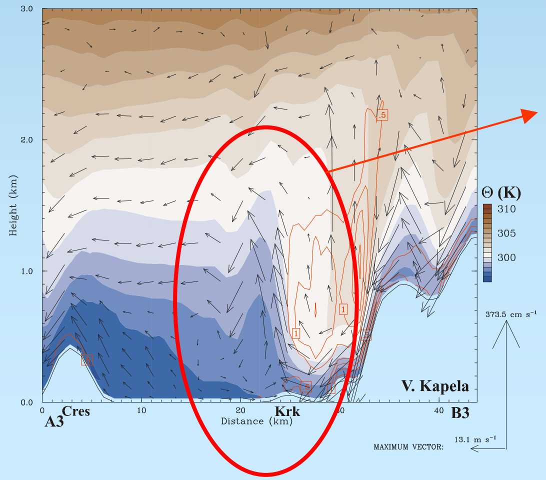


17:00 LT



Cross-section near Malinska of the modelled wind (m s^{-1}), the potential temperature (K) and TKE (m^2s^{-2})





the bottom branch of the lee rotor that was associated with the hydraulic jump

Sea/land breeze and air quality

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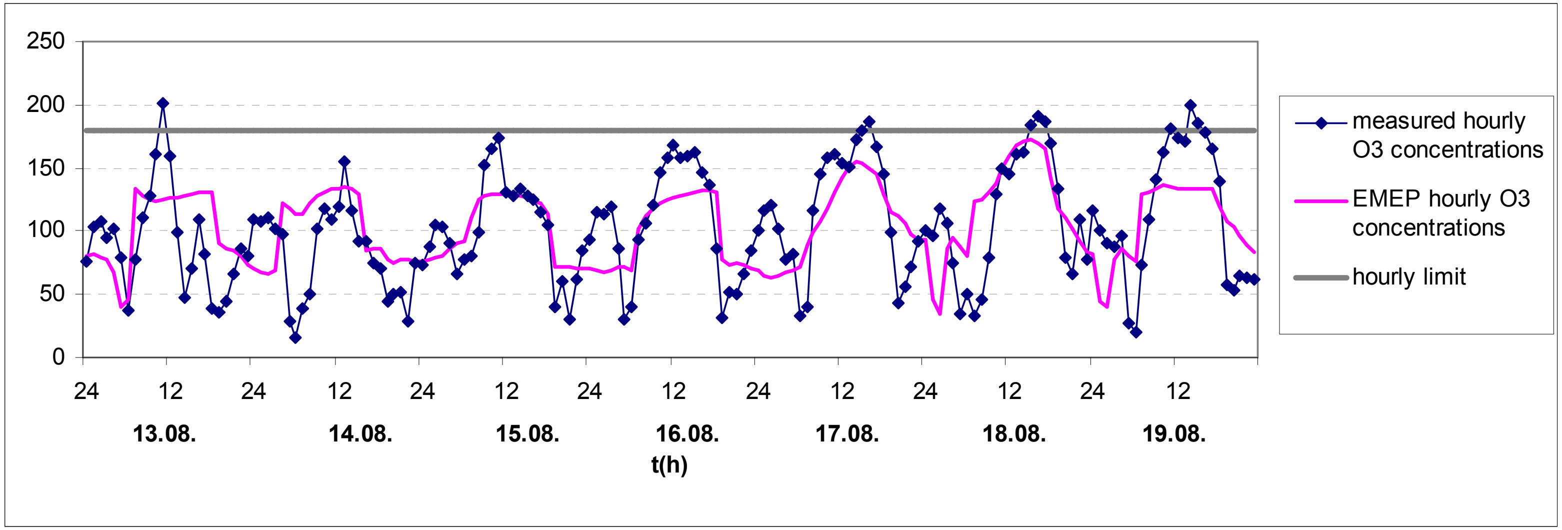
Sometimes unusually high ozone levels were detected
e.g, **13 to 19 August 2000** in Rijeka



During the **daytime**: the hourly ozone measurements exceeded consistently an information threshold of pollutant concentrations (180 $\mu g\ m^{-3}$)

During the **nighttime**, the ozone concentrations were unusually very high as well, above 100 $\mu g\ m^{-3}$.

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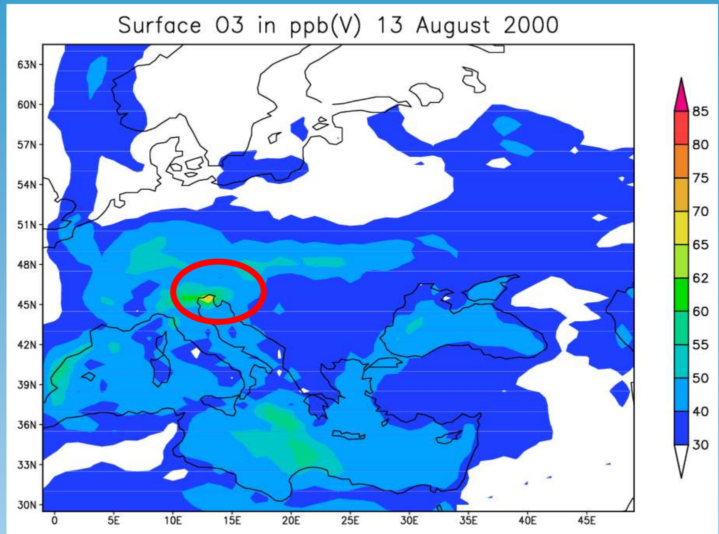
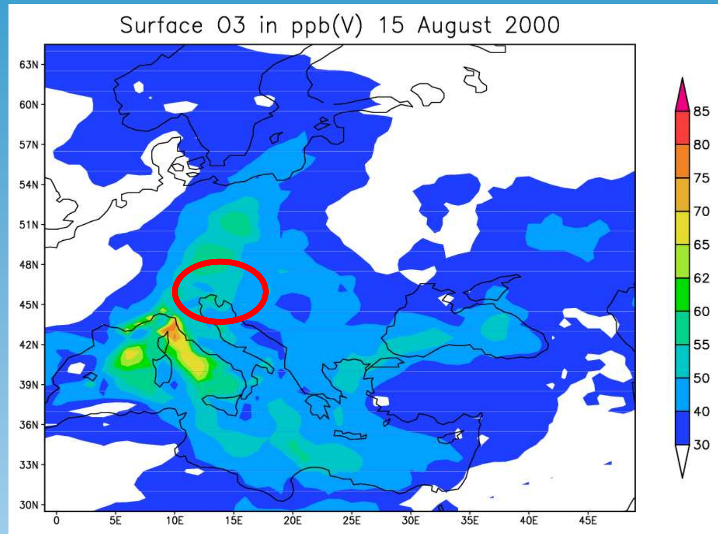
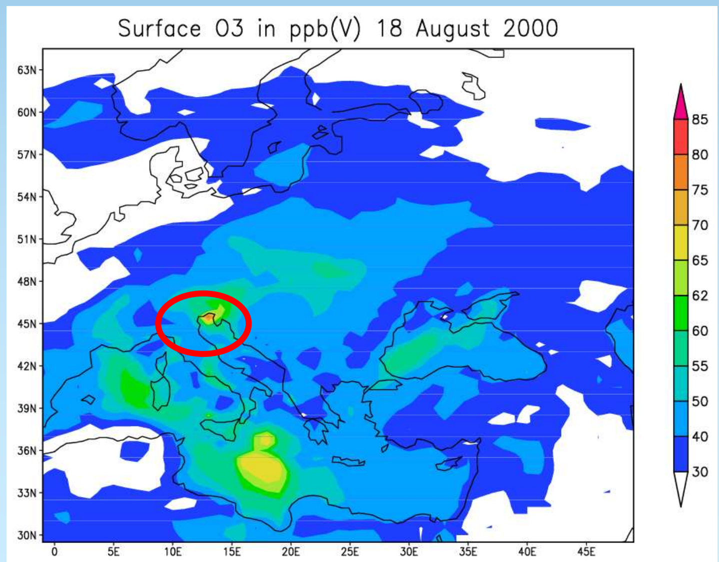
Sea/land breeze and air quality; EMEP model results

The horizontal distribution of daily mean surface EMEP O_3 concentrations (ppb)







The horizontal ozone distributions revealed the ozone maxima in the NE Adriatic within Gulf of Trieste on 13 and 18 August 2000.

During weak bora event, this area had smaller concentrations.

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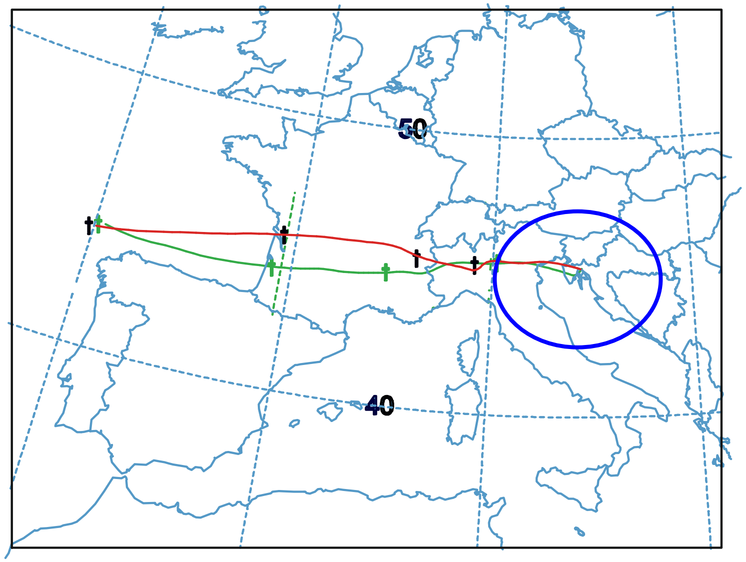
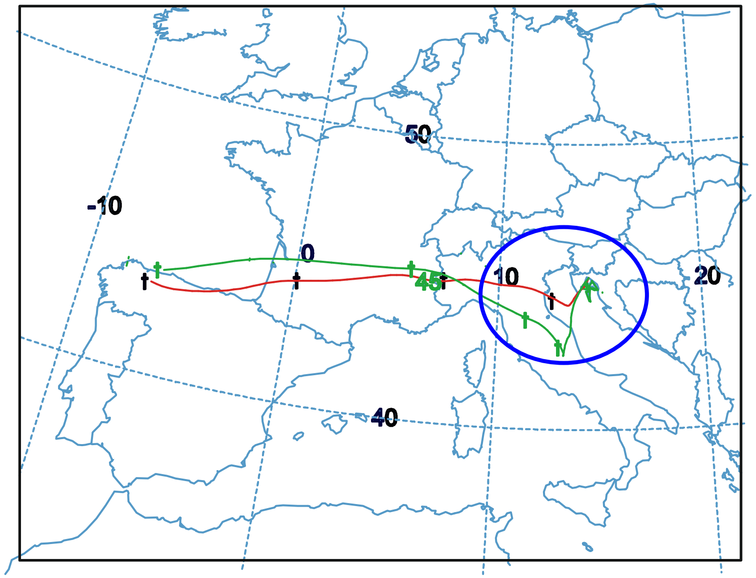
Sea/land breeze and air quality; EMEP trajectories

Backward trajectory ending at 00 UTC (red) and 12 UTC (green) 18 Aug 00



Trajectories exhibited that transboundary polluted air was crossing above known main regional emission sources of NOx and O_3; in Italy over Po river valley.

Backward trajectory ending at 00 UTC (red) and 12 UTC (green) 19 Aug 00



The WRF trajectories

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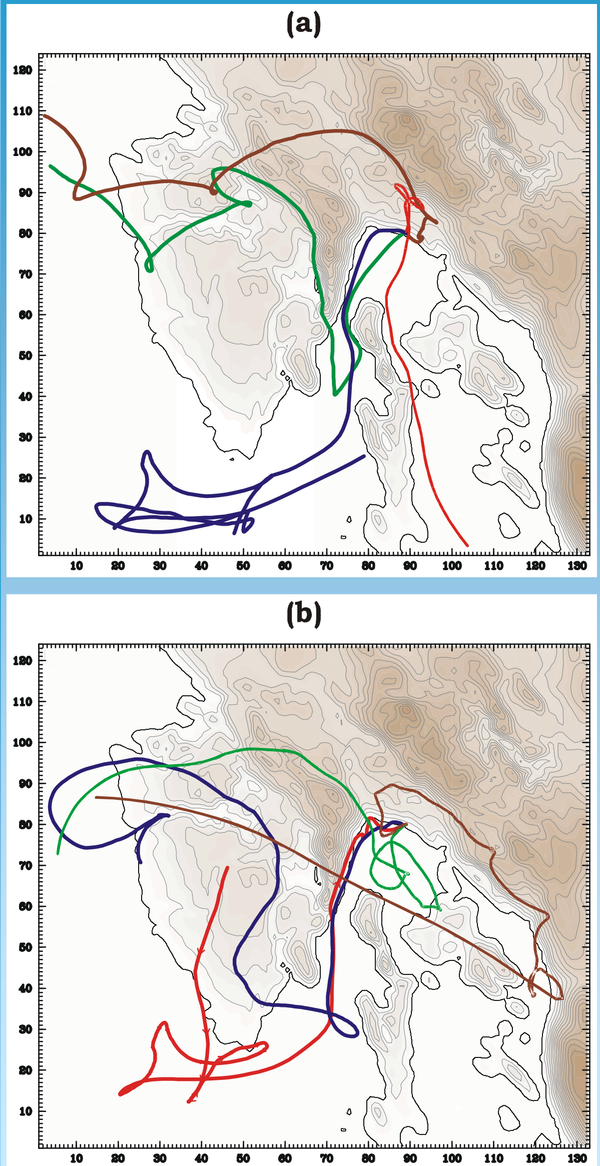

Plausible ways how the ozone reached the Rijeka area:

1) The ozone originated from Gulf of Trieste (northern Adriatic Sea) was carried by the western sea breeze and then was caught by the convergence zone above Istria.

During the nighttime, it was transported by the land breeze eastward over the sea, parallel to the Istria peninsula.

The channelized thermal daytime flow through the sea pass carried the ozone horizontally to the Rijeka Bay.

2) Ozone that was northward from convergence zone over Istria, was transported through the valley between Ćićarija and Risnjak toward Rijeka.

2-day backward 1000 hPa trajectories arriving at Rijeka every six hours (02 LST (red), 08 LST (brown), 14 LST (green) and 20 LST (blue)) starting from (a) 18 August 2000 and continue on (b) 19 August 2000. Parcel positions are given for every second hour for the wind field in the 1-km WRF domain.

Future steps: the fine scale air quality modeling at 1 km resolution; focus on the nighttime and daytime maxima

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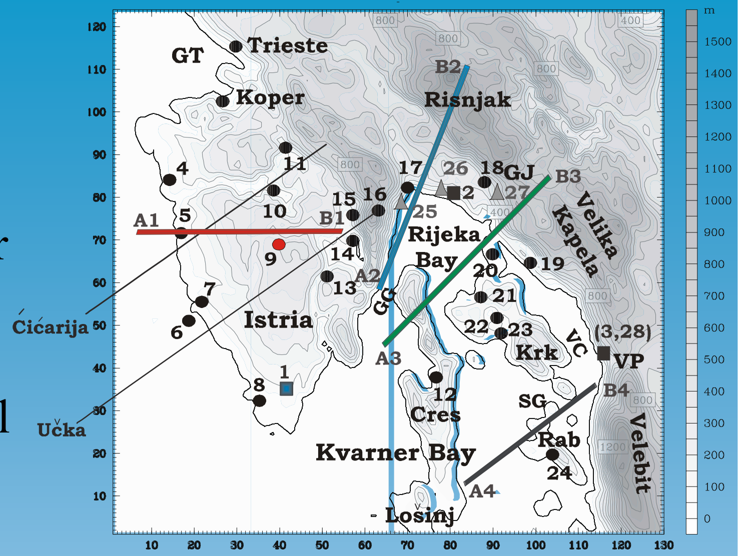
Sea/land breeze & CB over Istria

Istria:

- area with the highest frequency of thunder in Croatia
- Istrian CZ ⇒ depth ~ 1800 m
- extends along the peninsula almost parallel to the N-S axis



A climatological relationship between a sea breeze on the coast and a cumulonimbus over the Istrian peninsula.

Analysis at two stations: Pula-airport and Pazin

Period: 1997-2006 (from June to September).

Measurements: 1) 10-m wind
2) 2-m air temperature
3) SST
4) cloudiness

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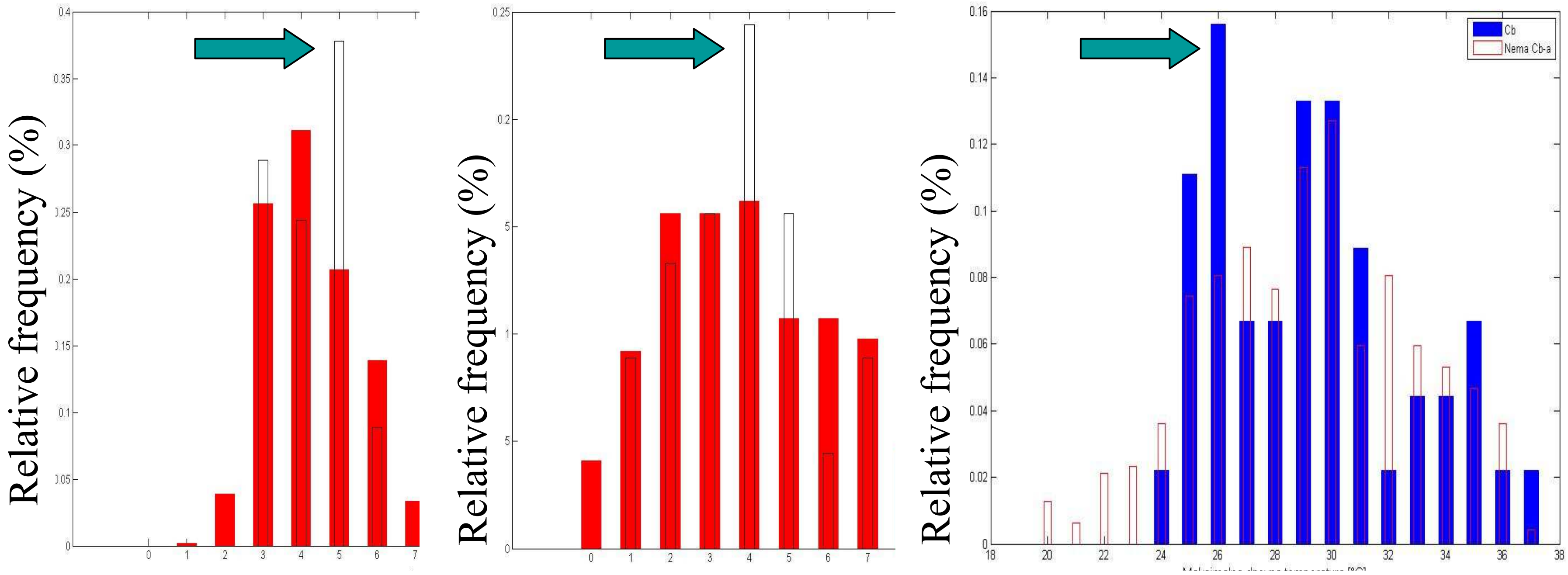
Sea/land breeze & CB over Istria

Pula- airport		Pazin		Pula-airport ∩ Pazin
Number of analyzed SLB days	SLB frequency (%)	Number of days with daytime* Cb in Pazin	Frequency of the daytime Cb (%)	Number of days with SLB and Cb
563	49	99	8	50

Daytime means hours between 10-20 UTC



Max SB wind speed (m s^{-1}) Max (sea-air) Δt (°C) Max 2-m temp (°C)

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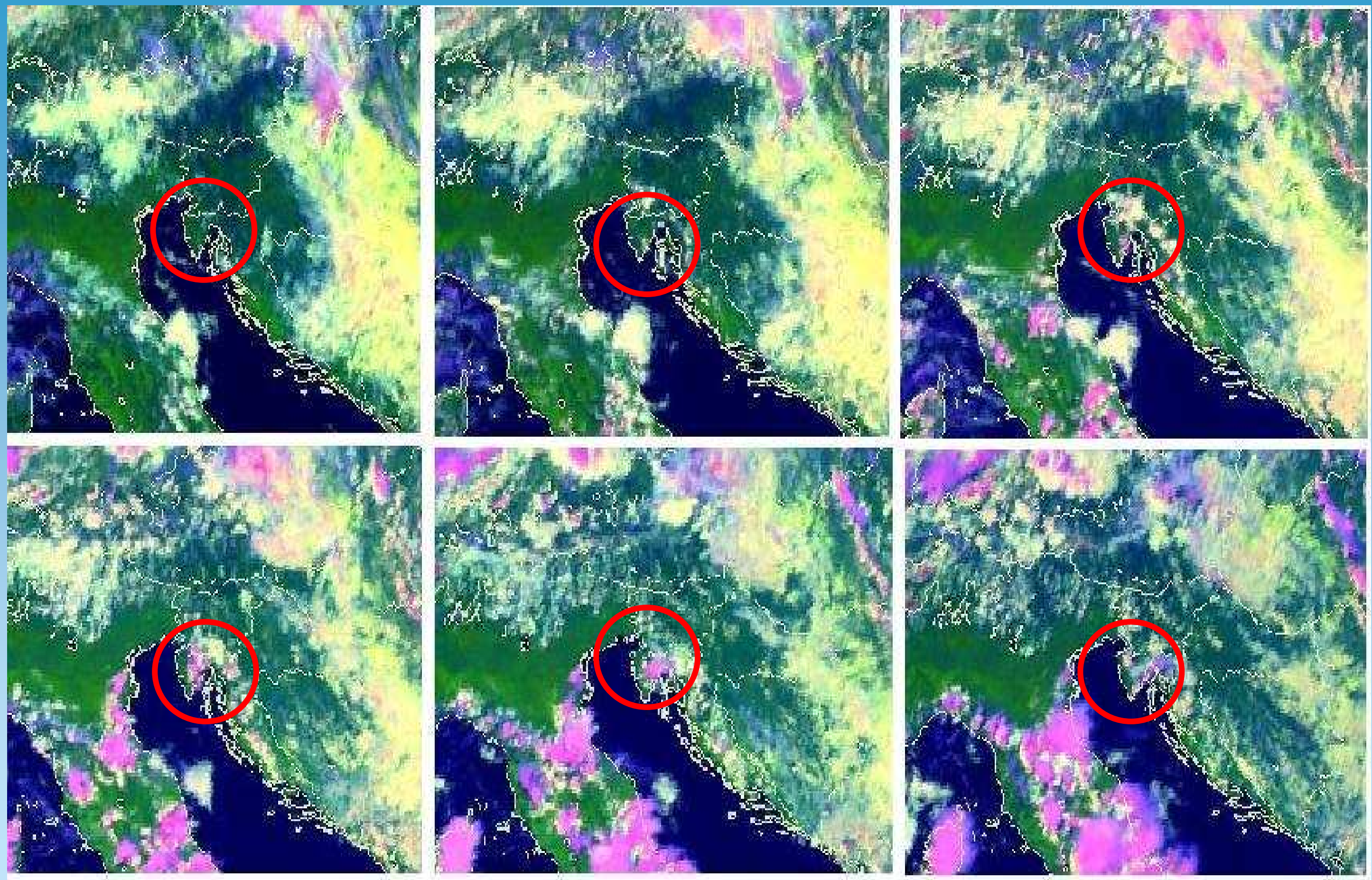
CB over Istria, 8 August 2006, CH 139, Meteosat 8

UTC +1 = CET

0900 UTC **1000 UTC** **1100 UTC**



1200 UTC **1300 UTC** **1400 UTC**

Cb usually form between noon and 2 p.m., lasting in general 3 to 5 hours

Future steps: modeling at fine resolution

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TO BE CONTINUED….