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Cyclone trackinng and wind tracking

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Cyclone Tracking
and
wind tracking

a short introduction

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Identification and tracking of mid-latitude cyclone systems:

Based on Murray & Simmonds (1991), adapted to Northern Hemisphere conditions by Pinto et al. (2005)

1. Identification
   a) Gridded MSLP field is transformed to a regular 0.75°x0.75° grid by a polar stereographic projection via bicubic spline interpolation

   b) This grid is scanned for maxima of the quasi-geostrophic relative vorticity via the Laplacian of pressure ($\nabla^2 p$)

$$\xi = \frac{1}{\rho \cdot f} \nabla^2 p$$

   c) Iterative search of a pressure minimum in the vicinity of $\nabla^2 p$
   d) Removal of systems on basis of specific thresholds

Identification and tracking of mid-latitude cyclone systems:

Based on Murray & Simmonds (1991), adapted to Northern Hemisphere conditions by Pinto et al. (2005)

2. Tracking

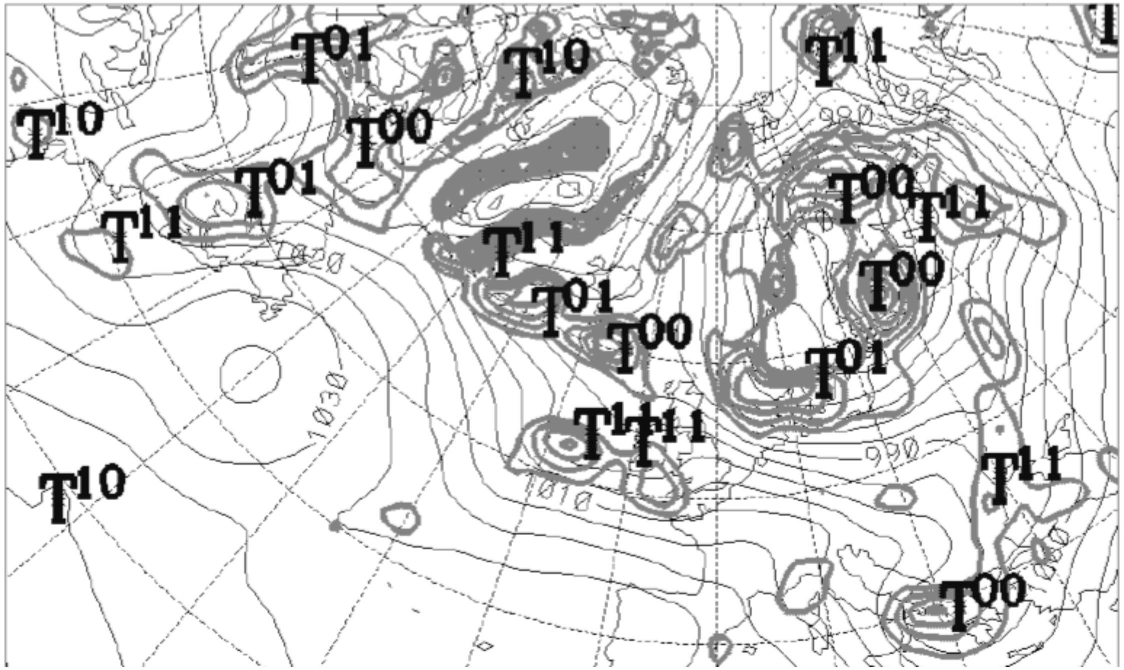
a) For each identified cyclone a subsequent position and core pressure is predicted by using a ***prediction velocity***, which is an average of the velocity deduced from the previous displacement and a geostrophic steering velocity

b) Geostrophic steering velocity (surface level) is calculated from an averaged pressure gradient around the centre of the cyclone over a radius of 4° of latitude scaled with a fixed value due to higher wind speeds in upper levels

c) Only those tracks were considered in which cyclones have been “closed” and “strong (>0.7 hPa/deg²)” at least once in their lifetime

Sensitivities and applications of a cyclone tracking algorithm

Joaquim G. Pinto [1], U. Ulbrich [2], G. C. Leckebusch [2], M. Donat [2], K. M. Nissen [2], T. Spangehl [2], S. Ulbrich [1], S. Zacharias [1]



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Sensitivities and applications of a cyclone tracking algorithm

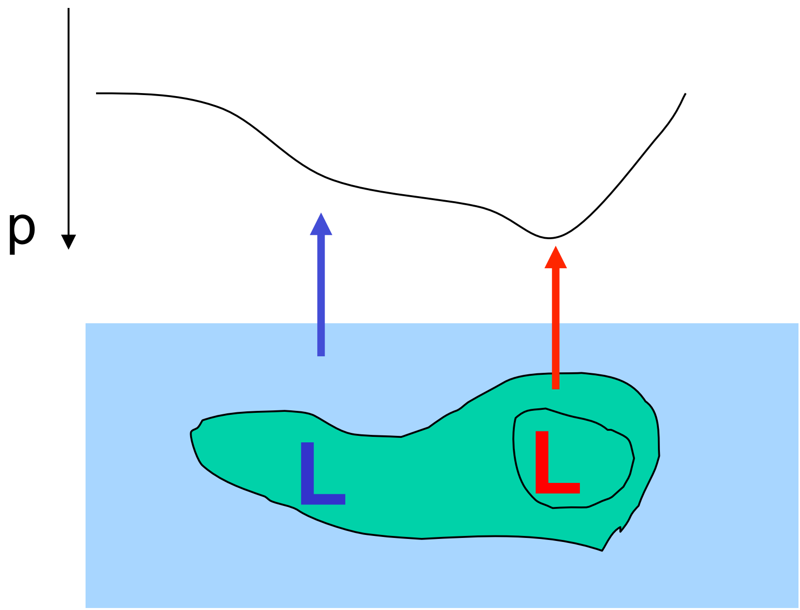
Outline:

1. Identification
2. Tracking
3. Case Study: Storm „Kyrill“ with different data resolutions
4. Other Applications
5. Conclusions

Cyclone Identification

(1) Identification from MSLP data but based on ∇^2p ($\xi = \frac{1}{\rho \cdot f}\nabla^2 p$)

(2) Differenciate between closed and open systems, threshould exceedance



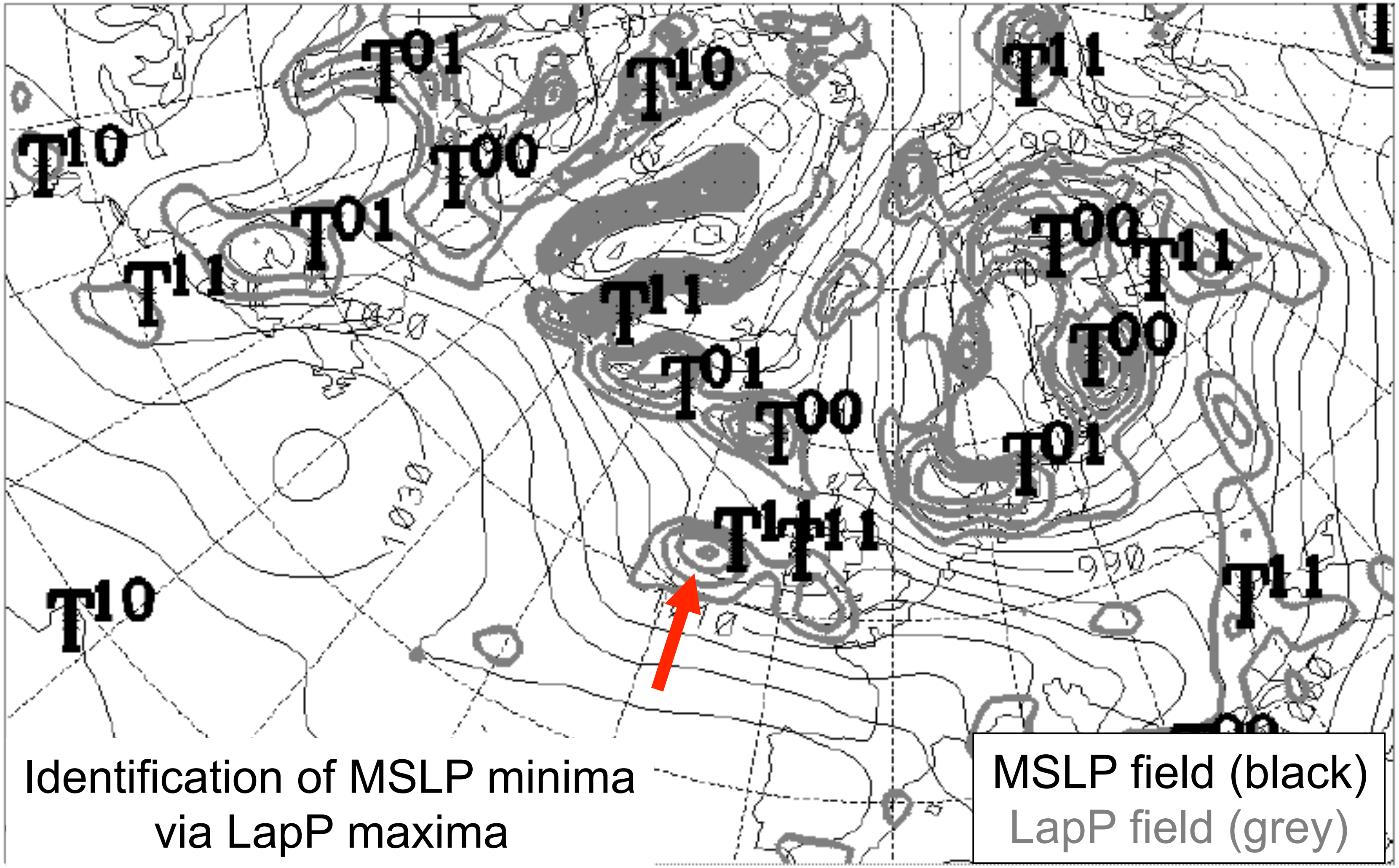
Closed: 0.1 *hPa deg.lat.*$^{-2}$

Open: 0.2 *hPa deg.lat.*$^{-2}$

(3) Cyclones removed if over high orography (> 1500 m)

Method based on Murray & Simmonds (1991), adapted to NH conditions by Pinto et al. (2005)

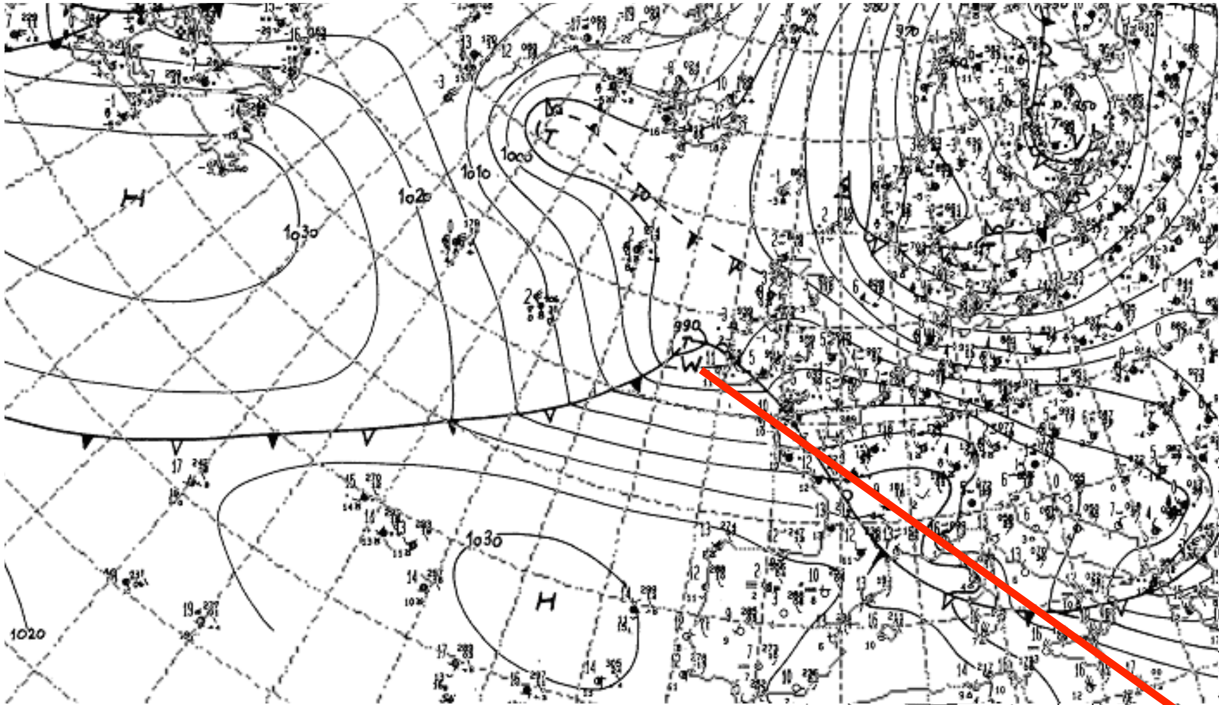
Identification of closed and open systems



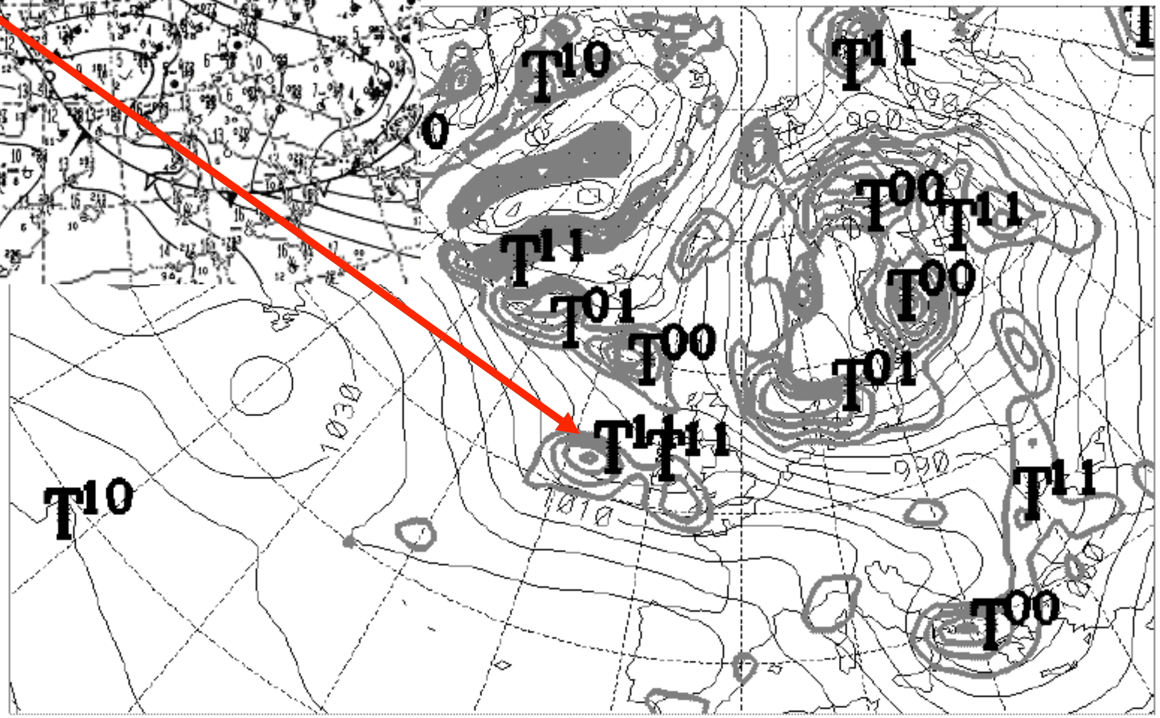
Pinto et al (2005) Met Z

Closed: T00 (strong), T10 (weak); Open: T01 (strong), T11 (weak)

Validation with weather charts



Example: Wiebke was an open system shortly before landfall, tracking otherwise difficult.



Pinto et al (2005) Met Z

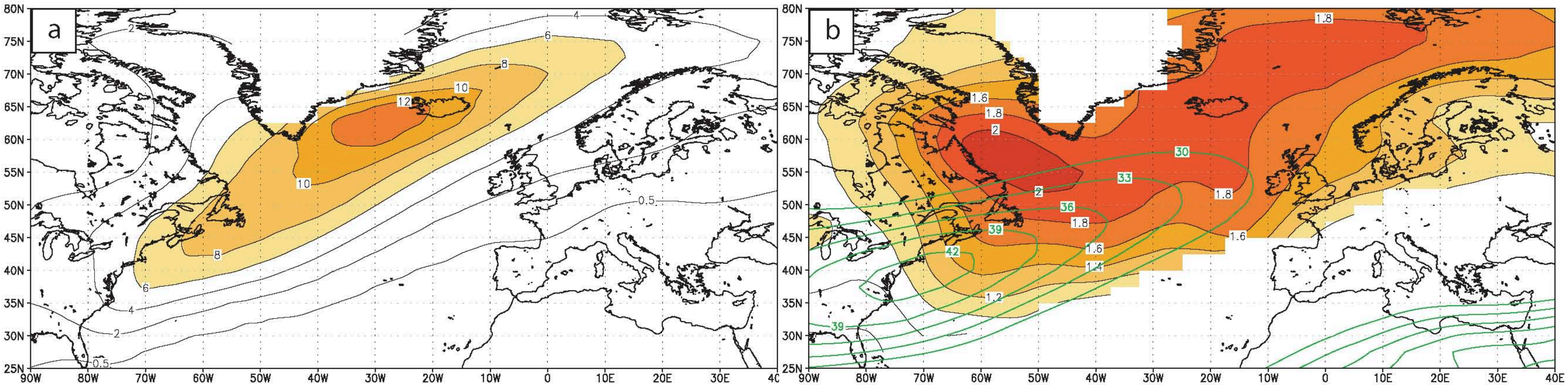
Closed: T00 (strong), T10 (weak); Open: T01 (strong), T11 (weak)

Cyclone Tracking / Manipulation / Statistics

(4) Tracking performed using an assignment algorithm for consecutive fields, the most probable solution is taken (via minimization of a cost function)

(5) Cyclones must have a lifetime of at least 24 hours

(6) Cyclone intensity (measured as $\nabla^2 p$) > 0.6 *hPa deg.lat.*$^{-2}$ and is associated "true" pressure minimum at least once during life time (T_{00})



Cyclone track density
10% strongest cyclones (>2,67 hPa/deg²)

Cyclone intensity

Pinto et al (2009) Clim Dyn

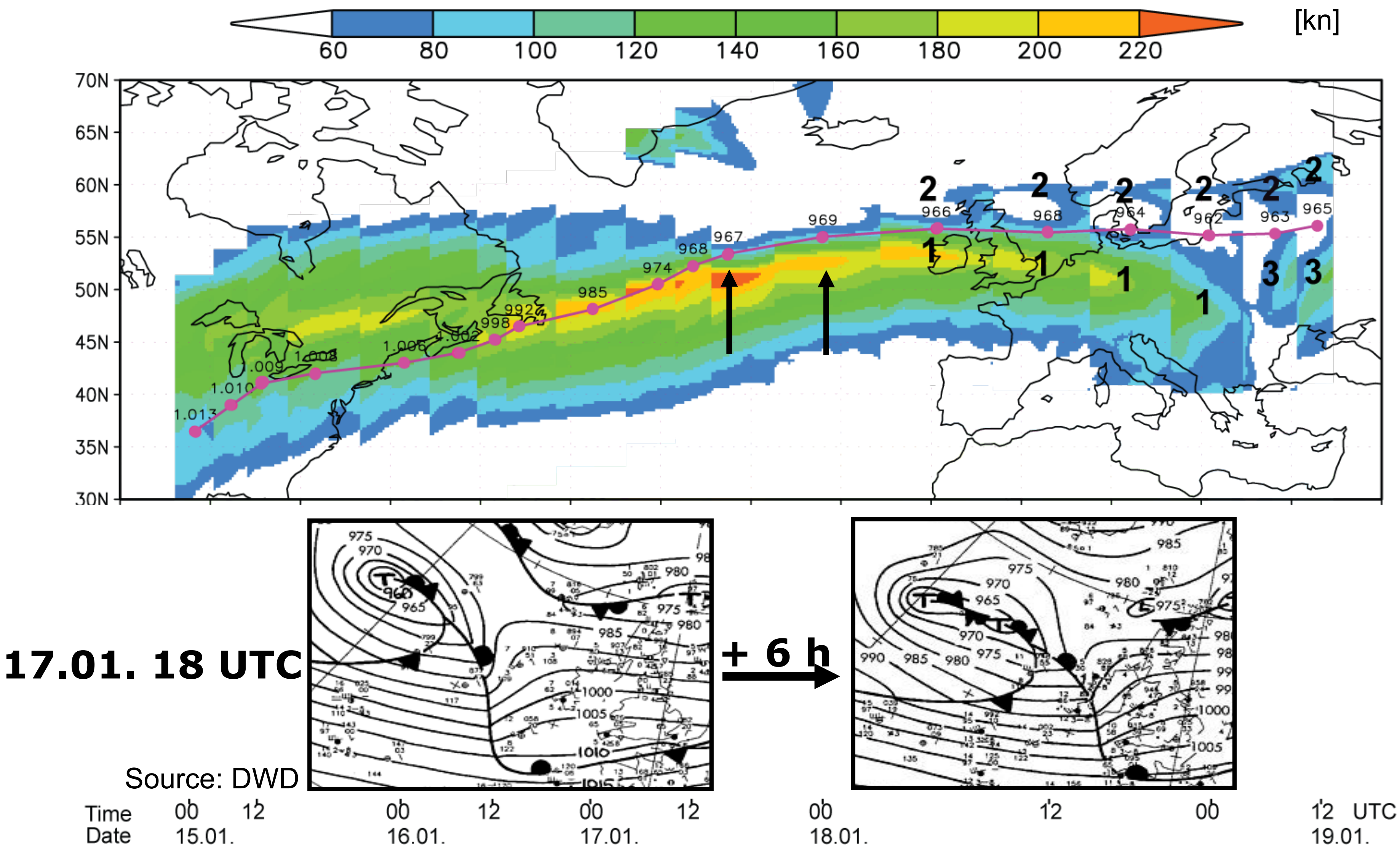
Evolution of cyclone characteristics over time (Daria)

Date	Time	Longitude	Latitude	Core Pressure	$\nabla^2 p$	d/dt (CP)	d/dt $(\nabla^2 p)$	#
19900123	00	303,85	40,42	1011,20	0,652	2,68	-0,110	
19900123	06	304,51	41,00	1010,81	0,719	-0,39	0,067	
19900123	12	306,03	42,07	1011,27	0,642	0,46	-0,077	
19900123	18	309,34	43,59	1008,94	0,818	-2,33	0,176	
19900124	00	315,81	45,69	1007,85	0,977	-1,09	0,159	
19900124	06	320,06	47,24	1002,83	1,095	-5,02	0,118	
19900124	12	325,74	48,48	996,82	1,339	-6,01	0,244	
19900124	18	333,36	49,84	986,66	1,600	-10,16	0,261	1
19900125	00	343,05	51,38	976,18	1,921	-10,48	0,321	2
19900125	06	350,40	53,23	963,70	2,218	-12,48	0,297	3
19900125	12	356,96	54,73	954,49	2,850	-9,21	0,632	4
19900125	18	1,98	56,17	946,98	3,432	-7,51	0,582	5
19900126	00	5,38	57,25	948,58	3,058	1,60	-0,374	
19900126	06	8,20	58,06	955,28	2,461	6,70	-0,597	
19900126	12	11,94	58,68	962,18	1,984	6,90	-0,477	
19900126	18	16,29	59,37	965,77	1,877	3,59	-0,107	
19900127	00	20,63	59,96	970,28	1,900	4,51	0,023	
19900127	06	24,92	61,11	974,15	1,731	3,87	-0,169	
19900127	12	28,16	61,85	978,62	1,396	4,47	-0,335	
19900127	18	32,34	62,90	982,81	1,070	4,19	-0,326	

Grey: maximum 24-hour intensification phase

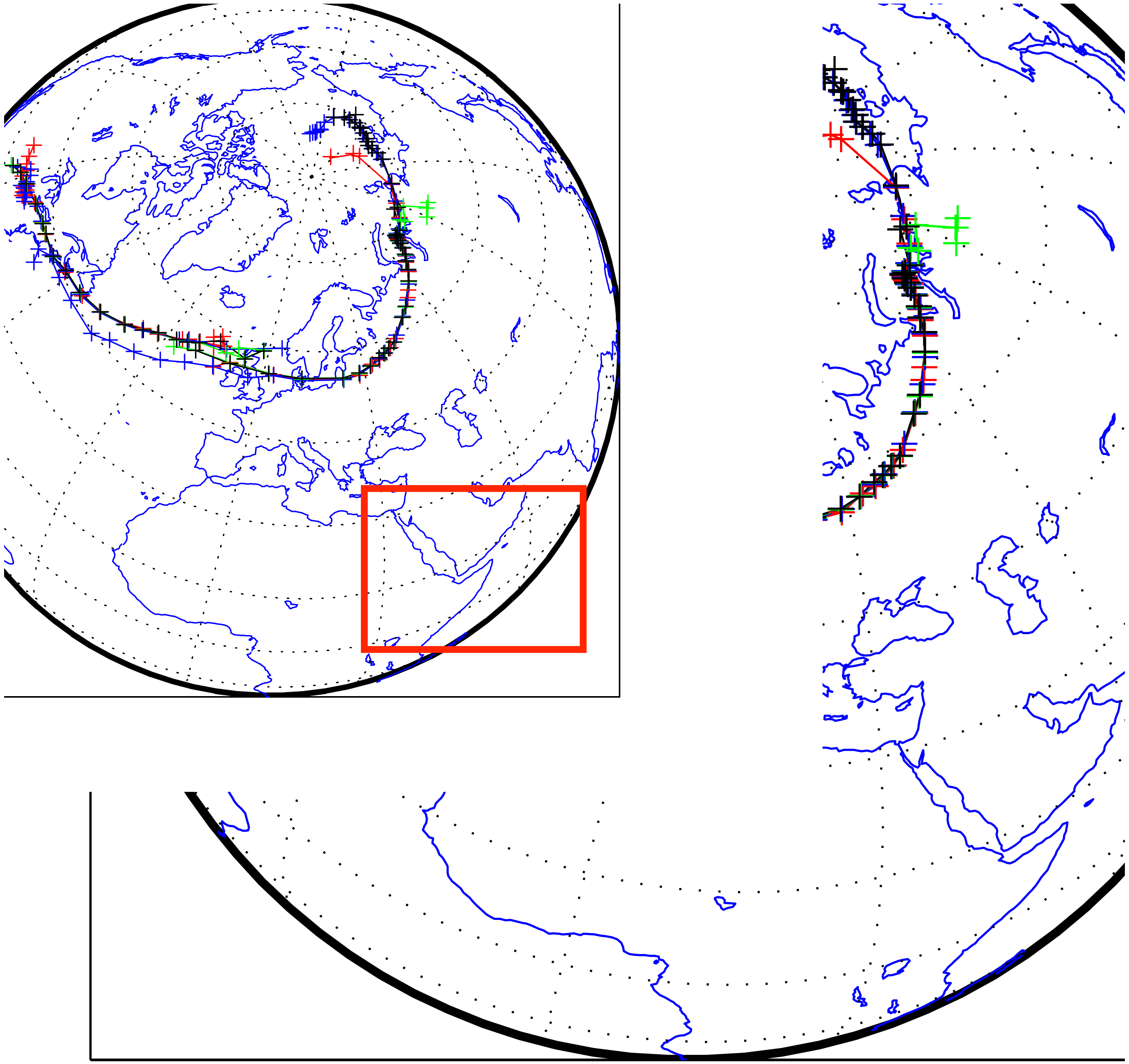
Pinto et al (2009) Clim Dyn

Example: European winter storm Kyrill (18.01.2007)



Fink et al (2009) NHESS:

Sensitivity studies for Kyrill with different resolutions



ERA-interim:

T63

T106

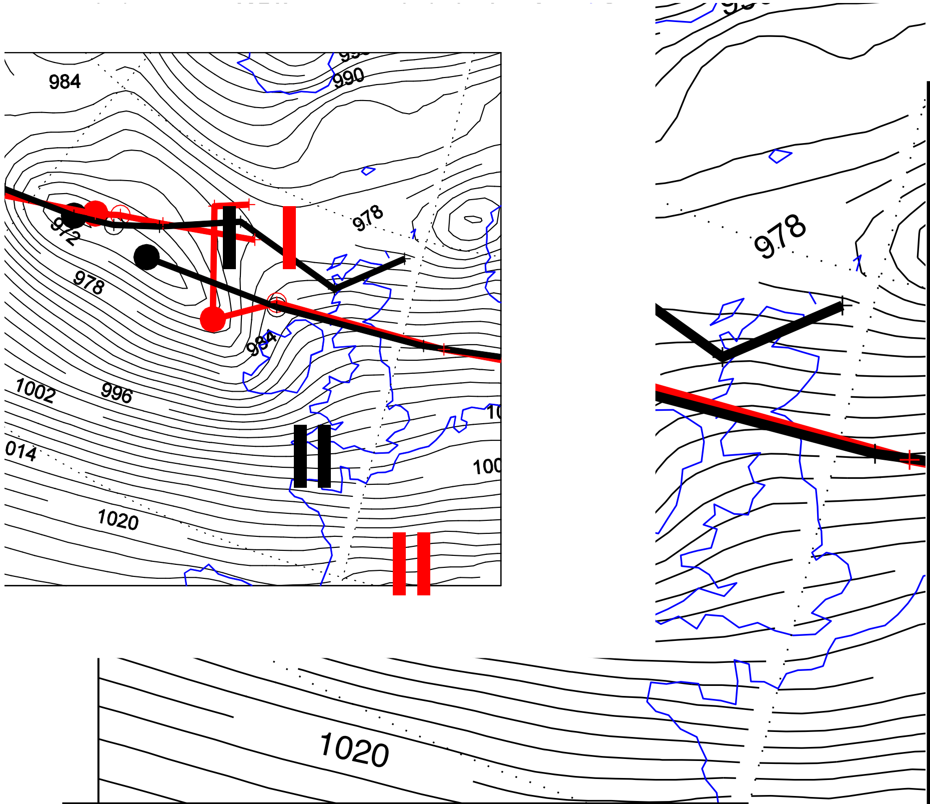
T159

T255

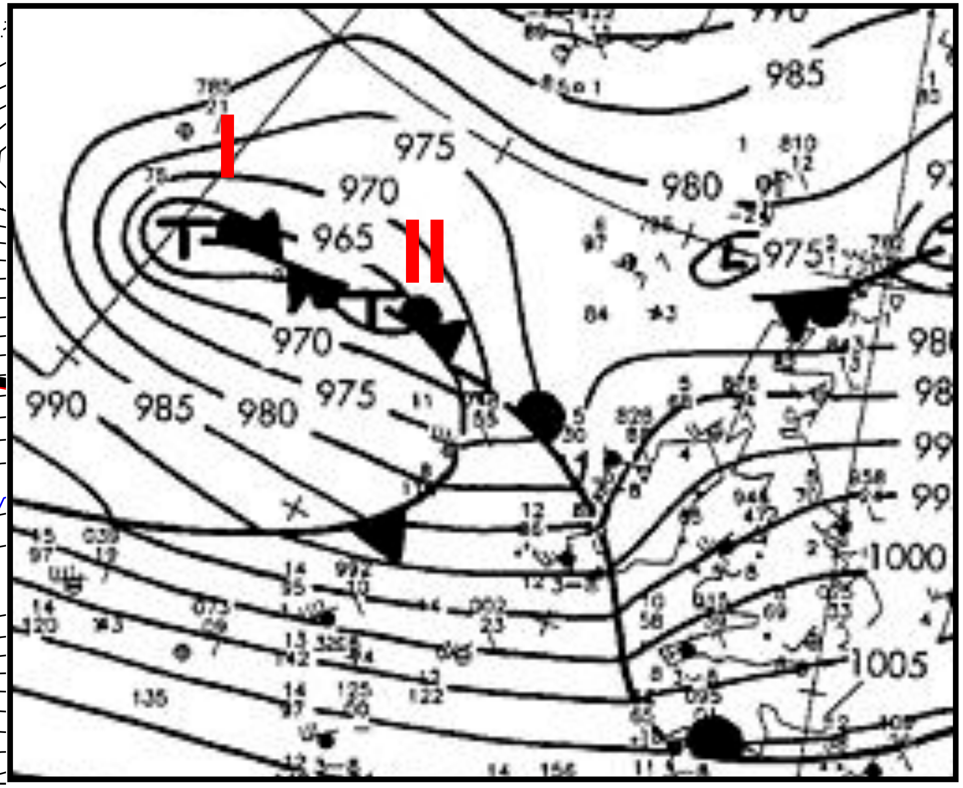
For t63,t106,t159
data was sprectraly
degraded from t255

Kyrill-I [-> 17.01 06 UTC]
Kyrill-II [17.01 00 UTC ->]

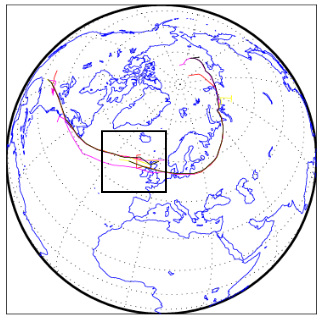
Sensitivity studies for Kyrill: comparison T63 vs T255



January 18th, 2007 00UTC



Source: DWD



I: 967,7 hPa

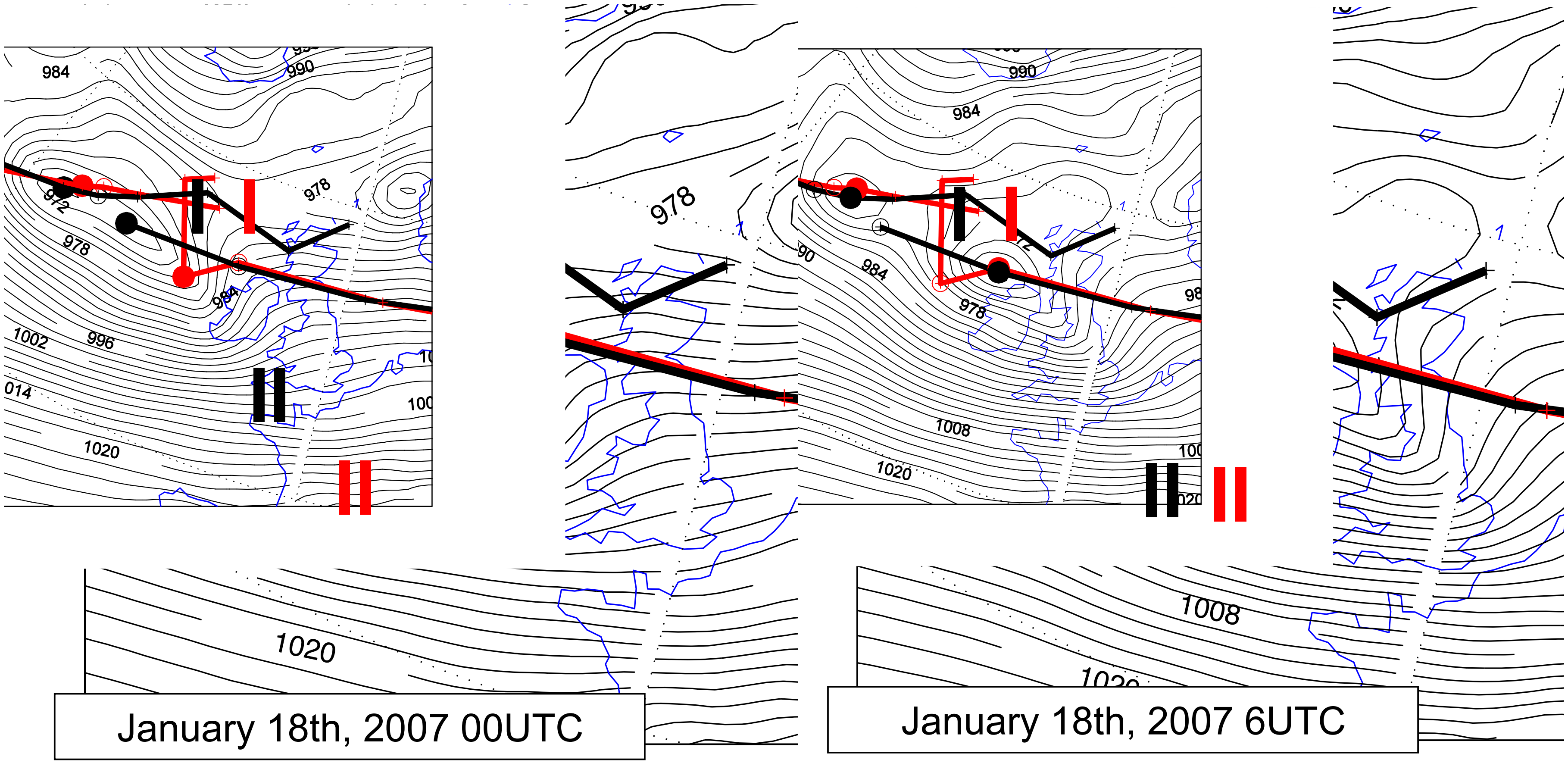
I: 969,7 hPa

II: T_{00} 968,5 hPa

II: T_{01} 976,0 hPa

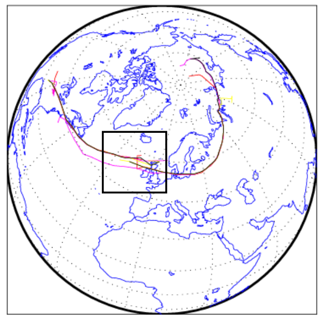
Tracks (Red: T63; Black T255), MSLP (contoured)

Sensitivity studies for Kyrill: comparison T63 vs T255



II: T_{00} 968,5 hPa
II: T_{01} 976,0 hPa

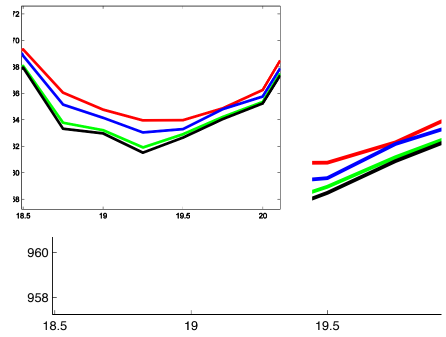
II: T_{00} 965,2 hPa
II: T_{00} 967,4 hPa



Tracks (Red: T63; Black T255), MSLP (contoured)

Sensitivity studies for Kyrill: Comparison core pressure

Day/H	T63	T106	T159	T255	DIFF
18/00	964,8	964,2	963,2	963,0	-1,8
06	964,0	963,0	961,9	961,5	-2,5
12	964,0	963,3	962,9	962,6	-1,3
18	964,9	964,8	964,2	964,1	-0,8
19/00	966,3	965,8	965,4	965,2	-1,0
06	971,4	970,6	970,3	970,1	-1,3
12	977,0	976,9	976,3	976,1	-0,8
18	980,8	980,5	980,1	979,9	-0,9
20/00	982,6	982,1	981,5	981,4	-1,2



Resolutions:

T63

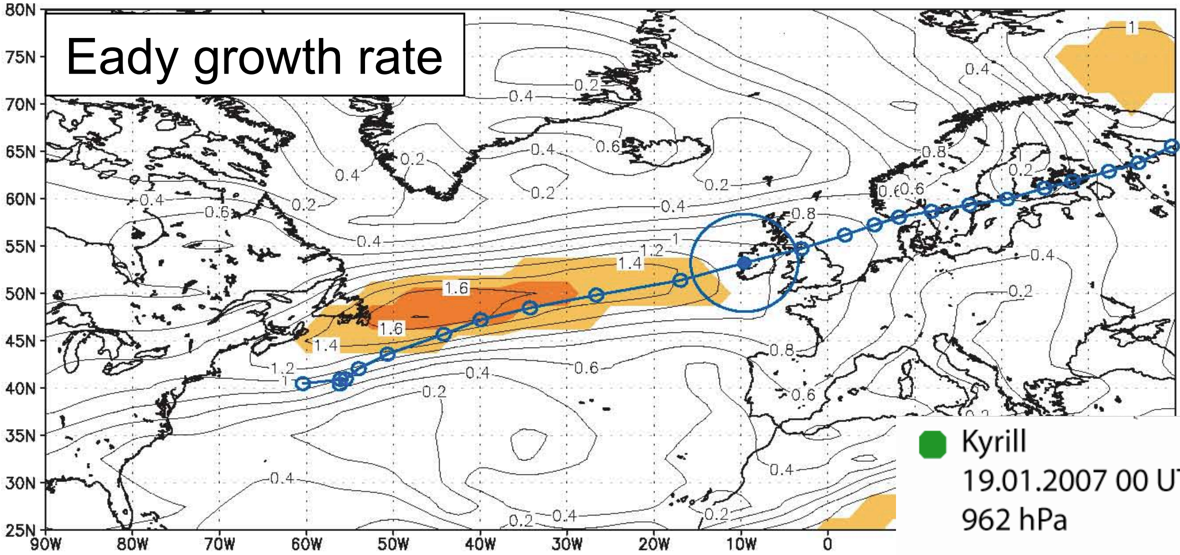
T106

T159

T255

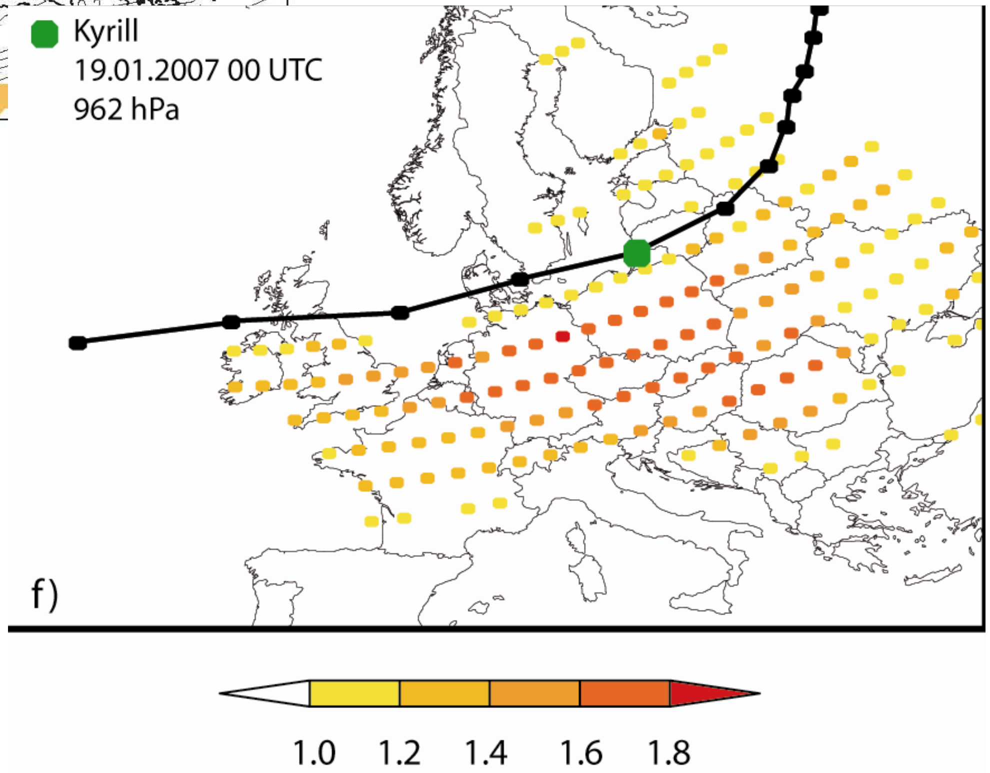
Important: take **data resolution** into account when comparing / validating cyclone statistics, e.g. GCM vs reanalysis data.

Applications: Intensification of cyclones / wind storm impacts



Intensification factors:
Latent Heat
Divergence 250 hPa
Eady growth rate 400 hPa
Jet Stream 250 hPa
Daily NAO-index

Wind signature for storm Kyrill
Exceedences of local 98th
Wind percentiles
->
Used to estimate storm losses



Climate change: tomorrow

Pinto et al (2009) Clim Dyn; Fink et al., 2009, NHESS

Summary

We use a cyclone track algorithm originally developed by Murray and Simmonds (1991) adapted to NH cyclone characteristics.

The scheme considers the cyclone laplacian of pressure (~ relative vorticity) on the first steps of cyclone intensification. Intensity measures are core pressure (CP) and laplacian of pressure (VOR)

The algorithm is capable of automatically tracking different types of cyclones at the same time (Important – open systems)

Results show a strong sensitivity to data resolution (here only spatial resolution investigated, example Kyrill)

Data permits a detailed description of cyclone life cycles. Applications:

> factors contributing to cyclone intensification

> associated wind fields and related impacts (losses / floods)

Step 1 - Identification

- Lows are normally regarded as pressure minima and are called closed depressions because they are surrounded by closed isobars

- But cyclonic disturbances may have locally large vorticity and may be meteorologically important without being associated with closed isobars

- Search for low in MSLP field or rather maxima of the pressure Laplacian

$$\xi = \frac{1}{\rho \cdot f} \nabla^2 p$$

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Step 1 - Identification

- Search for a pressure minimum in the vicinity of the Laplacian p maximum

- If such a minimum is found, the cyclone is classified as a **closed system,** with its core located at the pressure minimum

- If the search is not successful a second search is performed for the point with the minimum pressure gradient (inflection point), and the system is classified as an **open depression**

Step 1 - Identification

- Removal of systems ...
  - ... over high orography
    (probably artificial lows – because of extrapolation inaccuracies)
  - ... that do not have a minimum intensity
  - The presence of vorticity maxima along frontal zones and also in the vicinity of orography frequently leads to chains of open systems.
    Only the strongest system in a certain radius is included

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Step 2 - Tracking

- For each identified cyclone, the algorithm predicts a subsequent position and core pressure.
- The identified cyclones in the following time step which are located in the vicinity of the suggested position are examined and the most likely candidate is chosen.

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Step 2 - Tracking

- We will now work with those tracked cyclones

Track 7063: stat = 22, ifst = 466, ilst = 476, nit = 11 19571226 0600 - 19571228 1800. (itab= 2 1)

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
116.500	19571226	1200	44	48	1	0.358	325.080	65.530	981.360	0.972	4.778	-2.541
116.750	19571226	1800	44	61	0	0.572	324.790	65.640	983.060	0.843	4.937	-0.619
117.000	19571227	0	44	48	10	0.590	325.100	65.480	985.410	0.556	6.061	-0.316
117.250	19571227	600	44	52	0	0.595	328.990	65.540	986.960	1.387	8.868	-2.806
117.500	19571227	1200	44	50	1	0.498	333.040	67.230	990.590	1.093	3.179	-2.678
117.750	19571227	1800	44	51	11	0.500	337.260	65.410	996.480	0.506	6.765	-6.685
118.000	19571228	0	44	50	11	0.085	355.270	63.540	992.900	0.358	12.418	-6.821
118.250	19571228	600	44	51	11	0.390	2.810	62.530	991.920	0.300	10.119	-7.561
118.500	19571228	1200	44	59	11	0.561	10.960	61.760	990.030	0.423	2.392	-1.970
118.750	19571228	1800	42	62	11	0.182	23.790	57.170	995.610	0.447	19.059	0.171

Step 2 - Tracking

Track number — Track length [timesteps]

```
Track    7063: stat = 22, ifst =    466, ilst =    476, nit =   11 19571226 0600 - 19571228 1800. (itab= 2 1)
```

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
116.500	19571226	1200	44	48	1	0.358	325.080	65.530	981.360	0.972	4.778	-2.541
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118.500	19571228	1200	44	59	11	0.561	10.960	61.760	990.030	0.423	2.392	-1.970
118.750	19571228	1800	42	62	11	0.182	23.790	57.170	995.610	0.447	19.059	0.171

Step 2 - Tracking

Start date & hour

End date & hour

```
Track   7063:  stat = 22,  ifst =   466,  ilst =   476,  nit =   11 19571226 0600  19571228 1800.  (itab= 2 1)
```

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
116.500	19571226	1200	44	48	1	0.358	325.080	65.530	981.360	0.972	4.778	-2.541
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118.250	19571228	600	44	51	11	0.390	2.810	62.530	991.920	0.300	10.119	-7.561
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Step 2 - Tracking

Date and hour of current cyclone location

Track 7063: stat = 22, ifst = 466, ilst = 476, nit = 11 19571226 0600 - 19571228 1800. (itab= 2 1)

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
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117.000	19571227	0	44	48	10	0.590	325.100	65.480	985.410	0.556	6.061	-0.316
117.250	19571227	600	44	52	0	0.595	328.990	65.540	986.960	1.387	8.868	-2.806
117.500	19571227	1200	44	50	1	0.498	333.040	67.230	990.590	1.093	3.179	-2.678
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118.000	19571228	0	44	50	11	0.085	355.270	63.540	992.900	0.358	12.418	-6.821
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118.500	19571228	1200	44	59	11	0.561	10.960	61.760	990.030	0.423	2.392	-1.970
118.750	19571228	1800	42	62	11	0.182	23.790	57.170	995.610	0.447	19.059	0.171

Step 2 - Tracking

Classification of open/closed and
strong/weak system

Track 7063: stat = 22, ifst = 466, ilst = 476, nit = 11 19571226 0600 - 19571228 1800. (itab= 2 1)

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
116.500	19571226	1200	44	48	1	0.358	325.080	65.530	981.360	0.972	4.778	-2.541
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118.250	19571228	600	44	51	11	0.390	2.810	62.530	991.920	0.300	10.119	-7.561
118.500	19571228	1200	44	59	11	0.561	10.960	61.760	990.030	0.423	2.392	-1.970
118.750	19571228	1800	42	62	11	0.182	23.790	57.170	995.610	0.447	19.059	0.171

00 closed strong
01 open
strong
10 closed weak
11 open
weak

MedCLIVAR

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Step 2 - Tracking

Longitude and latidute

Track 7063: stat = 22, ifst = 466, ilst = 476, nit = 11 19571226 0600 - 19571228 1800. (itab= 2 1)

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
116.500	19571226	1200	44	48	1	0.358	325.080	65.530	981.360	0.972	4.778	-2.541
116.750	19571226	1800	44	61	0	0.572	324.790	65.640	983.060	0.843	4.937	-0.619
117.000	19571227	0	44	48	10	0.590	325.100	65.480	985.410	0.556	6.061	-0.316
117.250	19571227	600	44	52	0	0.595	328.990	65.540	986.960	1.387	8.868	-2.806
117.500	19571227	1200	44	50	1	0.498	333.040	67.230	990.590	1.093	3.179	-2.678
117.750	19571227	1800	44	51	11	0.500	337.260	65.410	996.480	0.506	6.765	-6.685
118.000	19571228	0	44	50	11	0.085	355.270	63.540	992.900	0.358	12.418	-6.821
118.250	19571228	600	44	51	11	0.390	2.810	62.530	991.920	0.300	10.119	-7.561
118.500	19571228	1200	44	59	11	0.561	10.960	61.760	990.030	0.423	2.392	-1.970
118.750	19571228	1800	42	62	11	0.182	23.790	57.170	995.610	0.447	19.059	0.171

Step 2 - Tracking

Core pressure (MSLP)

Track 7063: stat = 22, ifst = 466, ilst = 476, nit = 11 19571226 0600 - 19571228 1800. (itab= 2 1)

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
116.500	19571226	1200	44	48	1	0.358	325.080	65.530	981.360	0.972	4.778	-2.541
116.750	19571226	1800	44	61	0	0.572	324.790	65.640	983.060	0.843	4.937	-0.619
117.000	19571227	0	44	48	10	0.590	325.100	65.480	985.410	0.556	6.061	-0.316
117.250	19571227	600	44	52	0	0.595	328.990	65.540	986.960	1.387	8.868	-2.806
117.500	19571227	1200	44	50	1	0.498	333.040	67.230	990.590	1.093	3.179	-2.678
117.750	19571227	1800	44	51	11	0.500	337.260	65.410	996.480	0.506	6.765	-6.685
118.000	19571228	0	44	50	11	0.085	355.270	63.540	992.900	0.358	12.418	-6.821
118.250	19571228	600	44	51	11	0.390	2.810	62.530	991.920	0.300	10.119	-7.561
118.500	19571228	1200	44	59	11	0.561	10.960	61.760	990.030	0.423	2.392	-1.970
118.750	19571228	1800	42	62	11	0.182	23.790	57.170	995.610	0.447	19.059	0.171

Step 2 - Tracking

Laplacian of MSLP

Track 7063: stat = 22, ifst = 466, ilst = 476, nit = 11 19571226 0600 - 19571228 1800. (itab= 2 1)

t	da	hr	stat	k	iop	q	x	y	p	c	up	vp
116.250	19571226	600	24	52	1	0.000	325.260	64.720	976.190	1.584	9.079	-1.560
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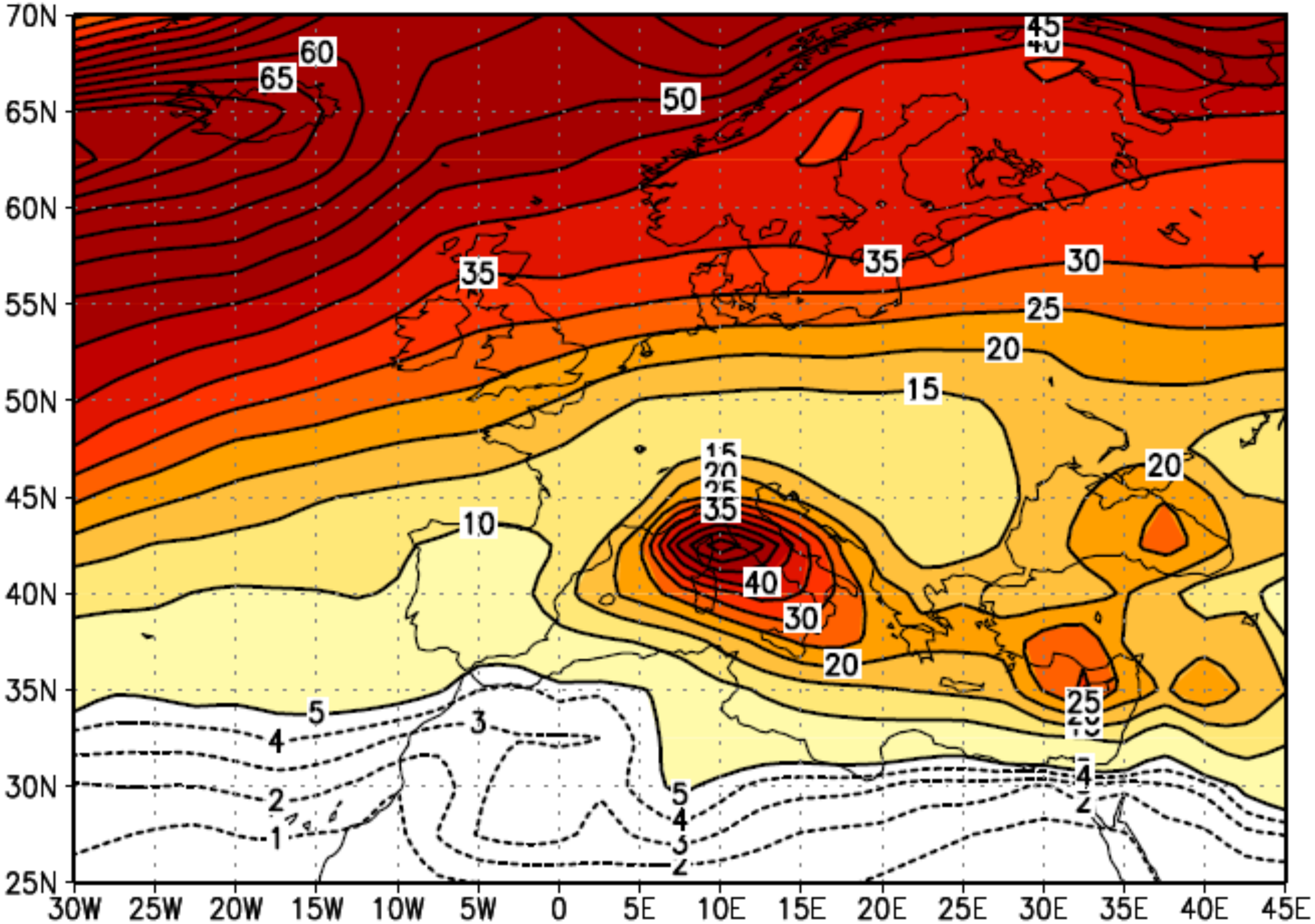
117.250	19571227	600	44	52	0	0.595	328.990	65.540	986.960	1.387	8.868	-2.806
117.500	19571227	1200	44	50	1	0.498	333.040	67.230	990.590	1.093	3.179	-2.678
117.750	19571227	1800	44	51	11	0.500	337.260	65.410	996.480	0.506	6.765	-6.685
118.000	19571228	0	44	50	11	0.085	355.270	63.540	992.900	0.358	12.418	-6.821
118.250	19571228	600	44	51	11	0.390	2.810	62.530	991.920	0.300	10.119	-7.561
118.500	19571228	1200	44	59	11	0.561	10.960	61.760	990.030	0.423	2.392	-1.970
118.750	19571228	1800	42	62	11	0.182	23.790	57.170	995.610	0.447	19.059	0.171

What kind of statistics can we do with such Cyclone Tracks?

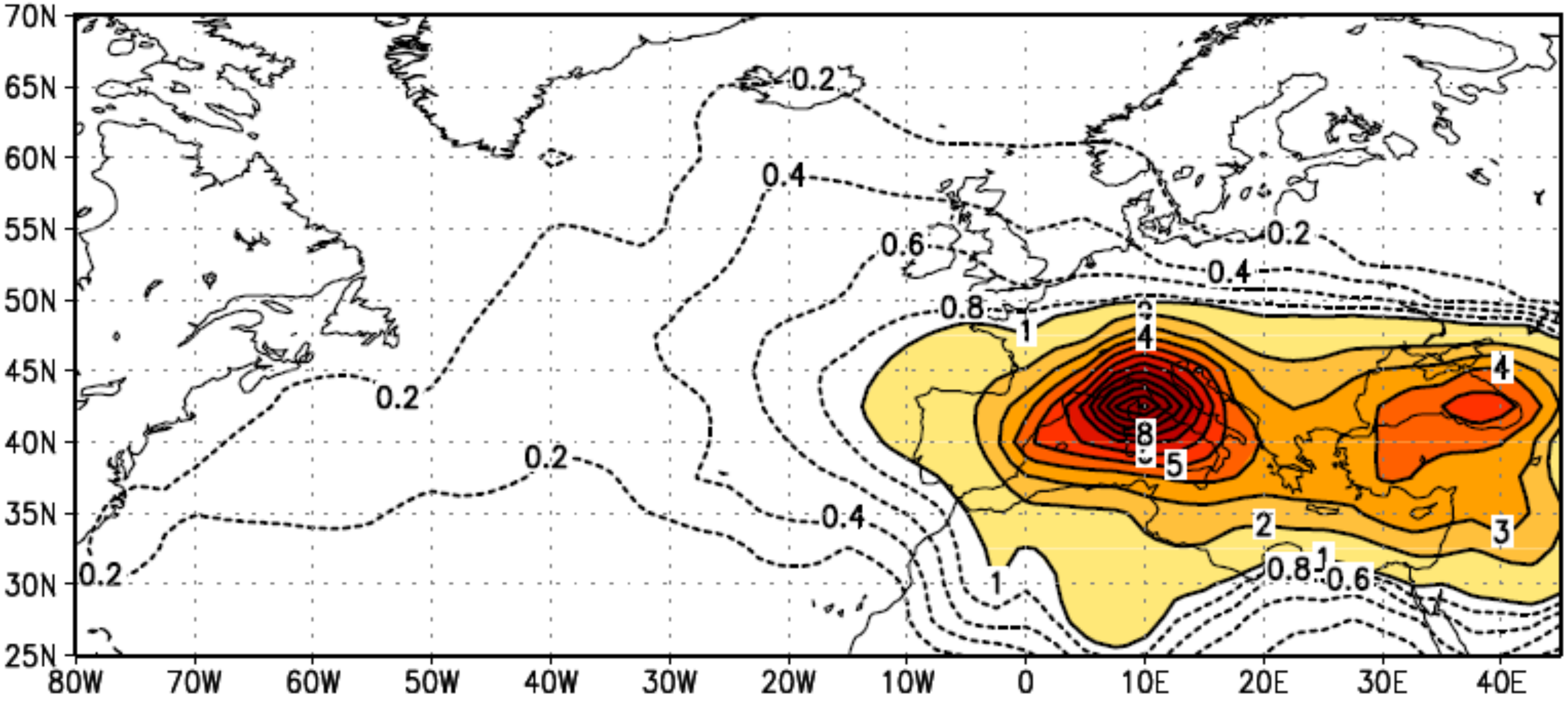
Following figures by
Nissen et al.
FU Berlin
Institute for Meteorology

Track density



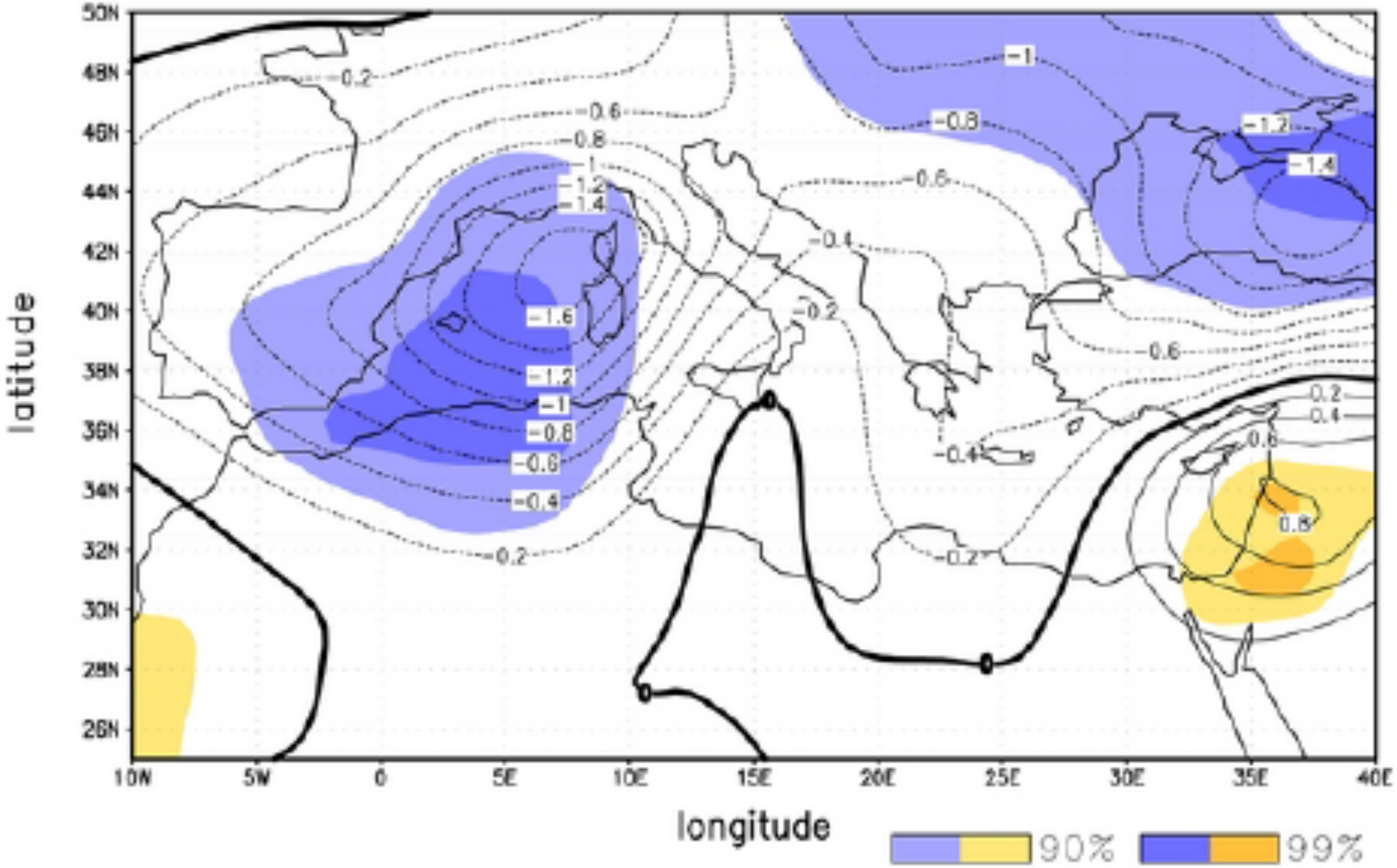
Number of cyclones per extended winter season (Oct-Mar) and lat^2

Cyclogenesis



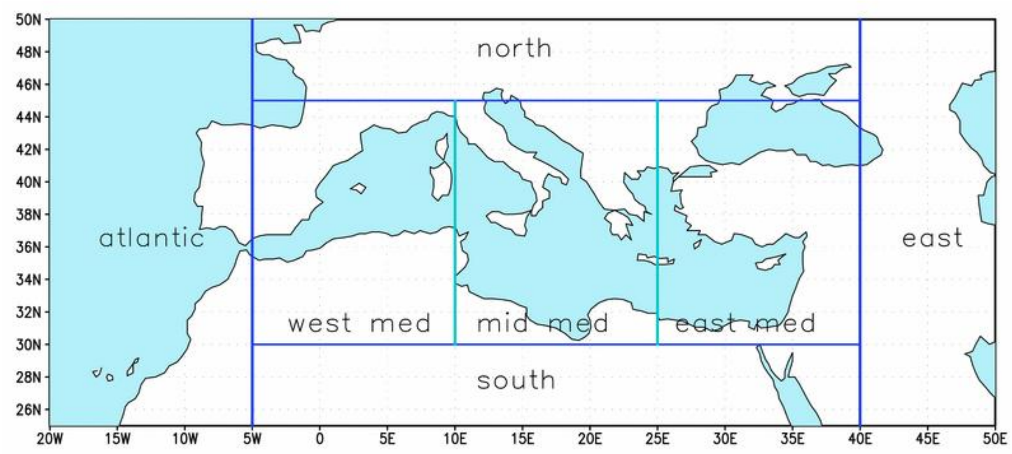
Region of cyclogenesis for cyclones crossing the Mediterranean region during the extended winter season. In events/winter/(deg.lat)^{2}.

Trend



Linear trend of cyclone track density 1957-2002 in number of winter cyclones per decade and per (deg.lat)².

Annual cycle frequency



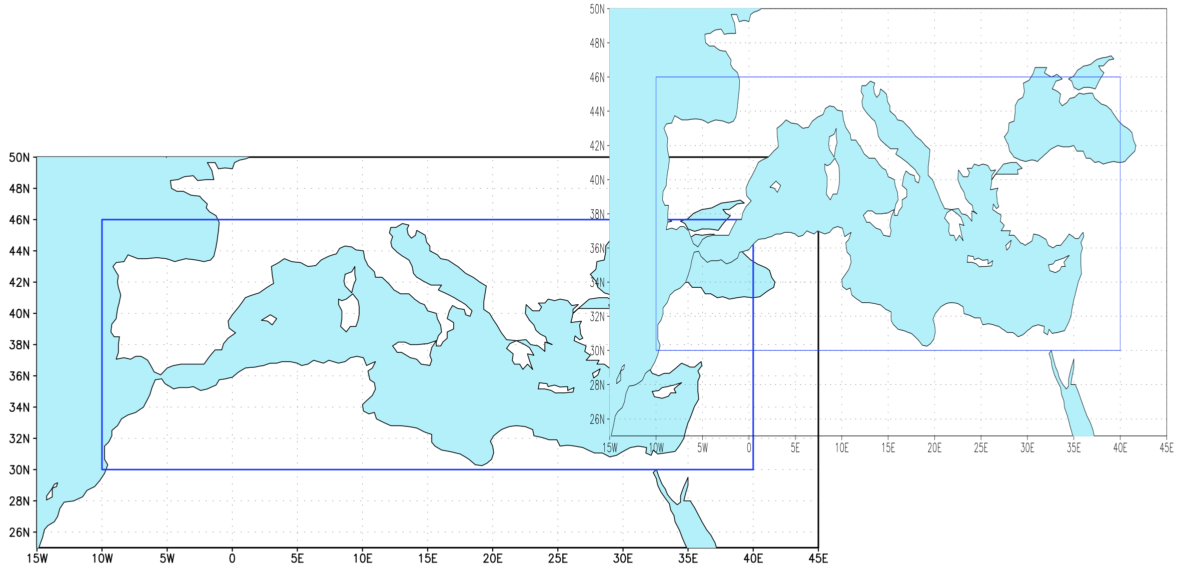
Number of cyclones per month originating in different regions.

Today's excercise

- List of precipitation events* in the area of the Mediterranean Sea
- Shell/FORTRAN/Matlab scripts** to create figures with
  - MSLP and precipitation field
  - the track of the corresponding cyclone

* Pinto et al.
** Nissen, Schuster

- o **INVESTIGATING:**
- o **Frequency and spatial distribution of**
- o **Cyclones**
- o **Wind tracks**
- o **Cyclones with wind track affecting the Mediterranean region**



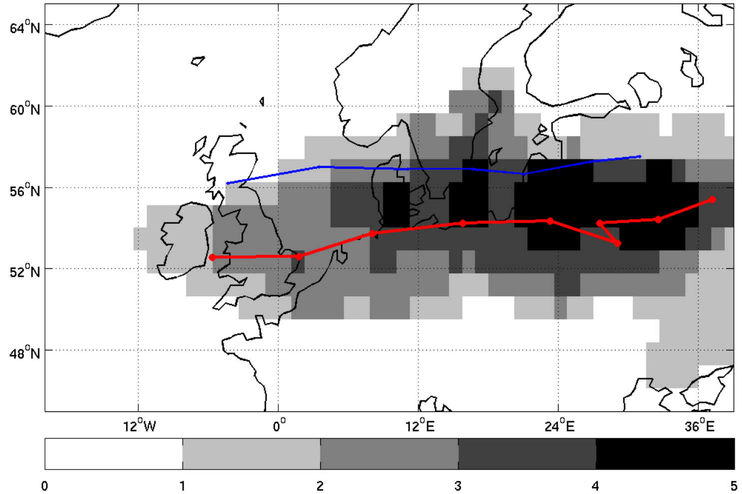
- o **Intensity of**
- o **Wind storms**

Analysis for the extended winter season (October-March)

WIND TRACKING AND CYLONE MATCHING

Freie Universität Berlin

Wind storm Anatol



From Leckebusch et al. 2008

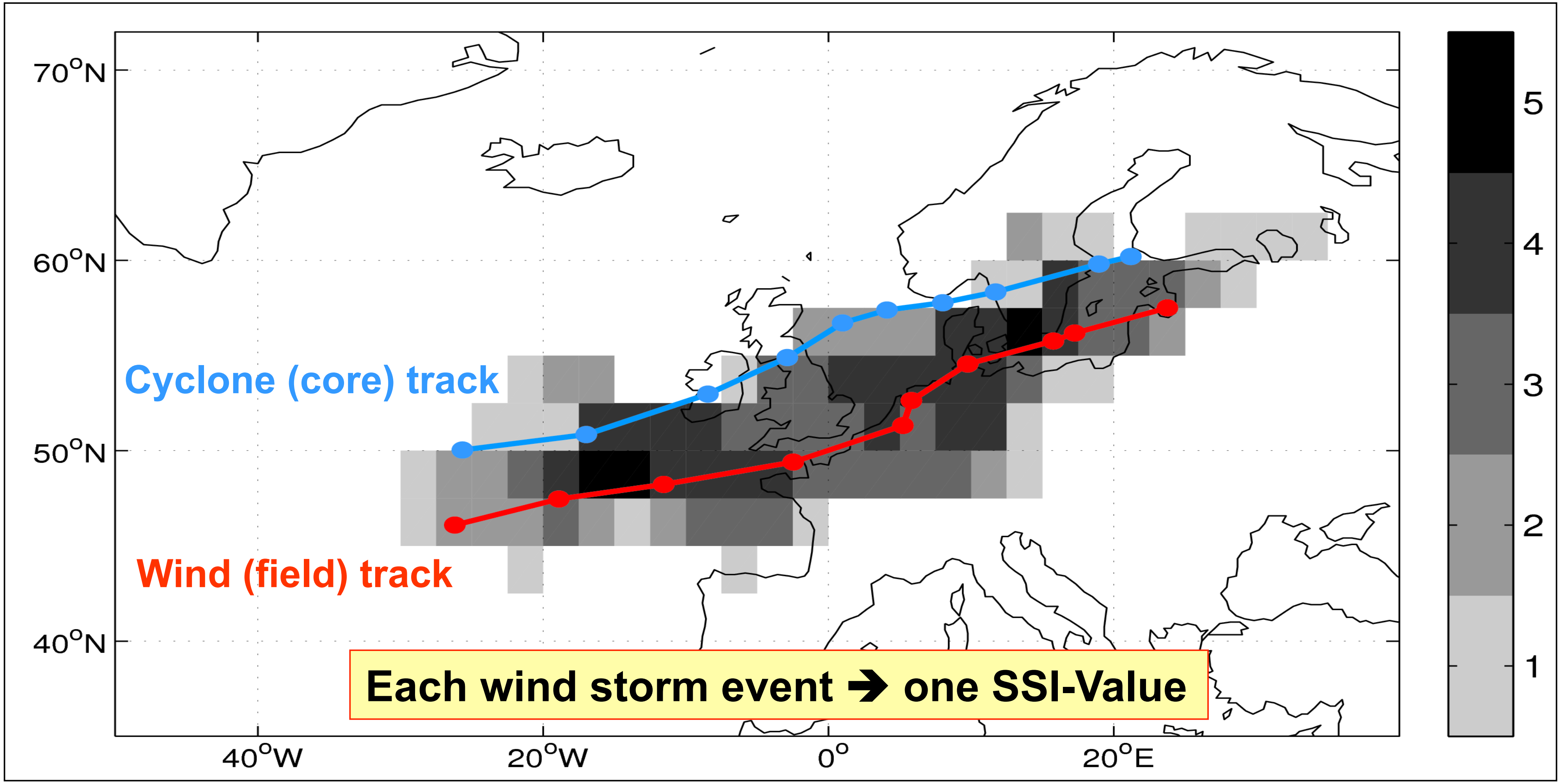
- o Searching for clusters of grid boxes where the wind speed exceedes the **local 98th percentile = EXTEME**.
- o Tracking of clusters with nearest neighbour approach (Leckebusch et al. 2010).
- o Minimum thresholds for area and duration
- o Cyclone associated with the wind track is selected from cyclone catalogue (Nissen et al. 2010).
- o Cyclone catalogue was compiled using Murray and Simmonds 1991, Pinto et al. 2005 technique, based on MSLP, $\nabla^2 p$.

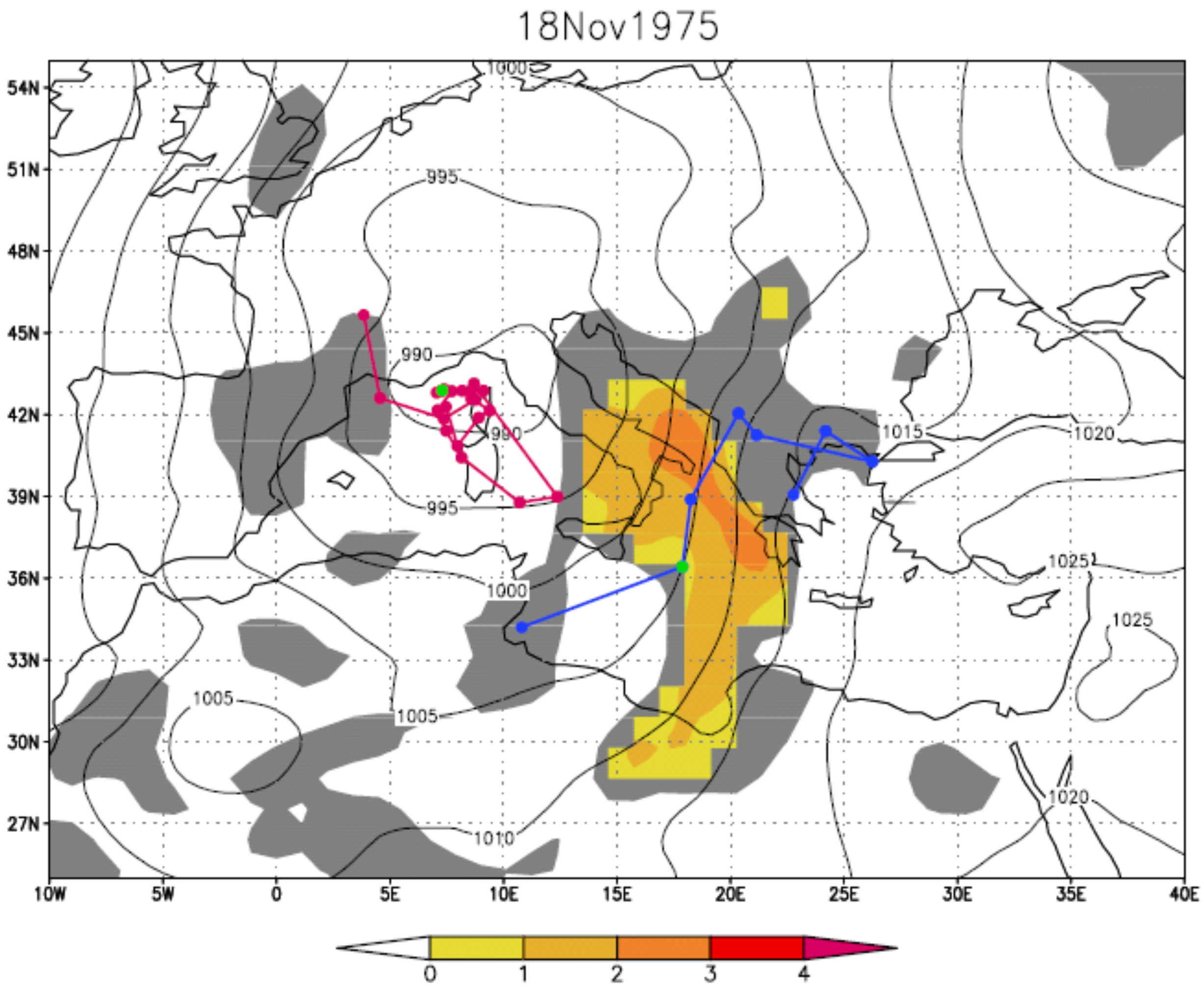
1. Synoptic aspects and Identification

Freie Universität Berlin

Track of wind storm "Daria" (24.01.1990–26.01.1990);

based on wind speed (red) and affected area (shading)
Shading: number of times a grid box was affected



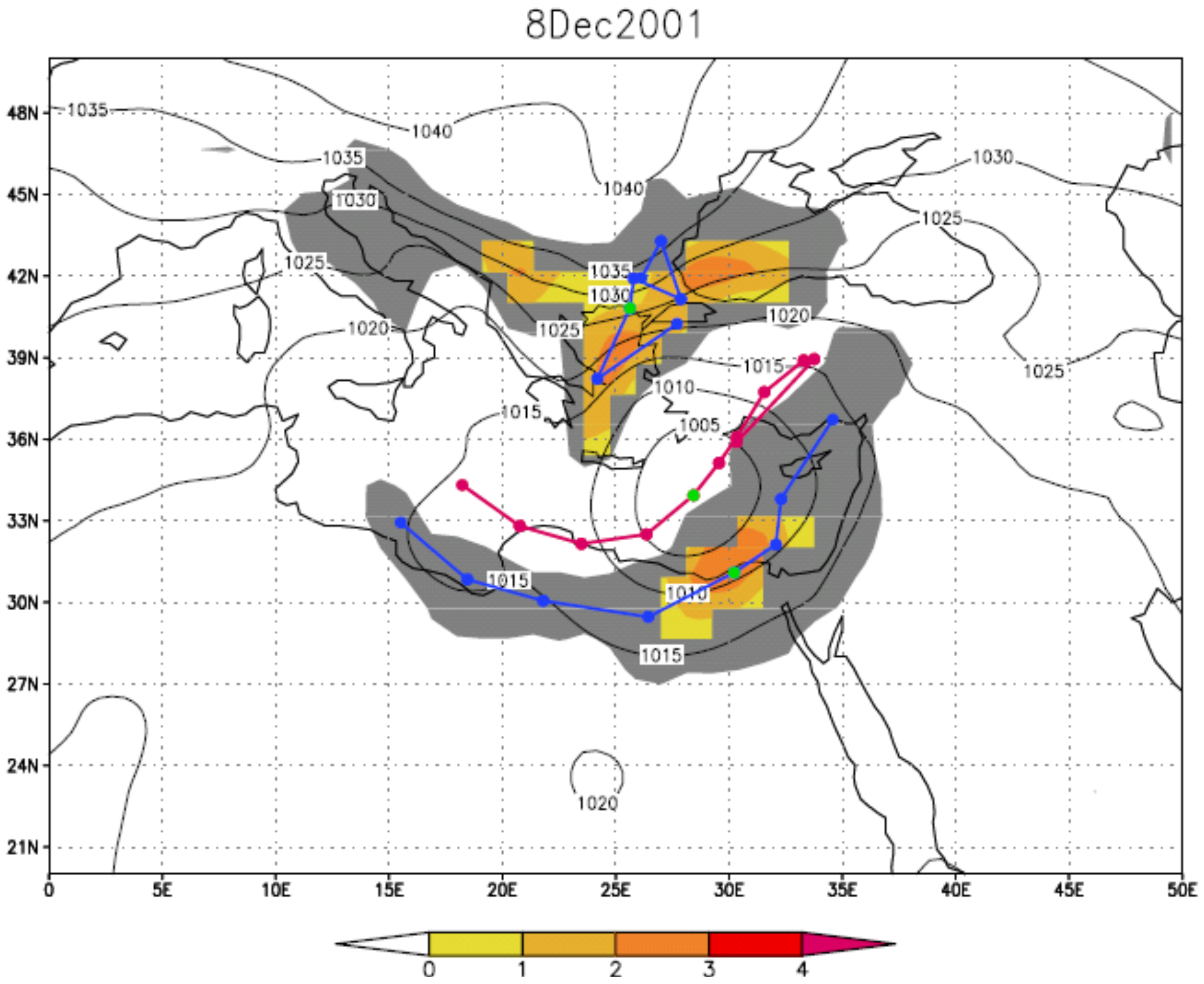


Cyclone track (red), wind-cluster track (blue), MSLP field (isolines in hPa) and exceedance of 98th percentileof wind speed (coloured shading in m/s above local 98th percentile)

18 November 1975 06:00.
Green dots:
current cyclone core and wind cluster centre.

The total area with wind speeds exceeding the 98th percentile over the 2 day period is shown in gray.

The event has caused flooding in Venice.



Cyclone track (red), wind-cluster track (blue), MSLP field (isolines in hPa) and exceedance of 98th percentileof wind speed (coloured shading in m/s above local 98th percentile)

Green dots:
current cyclone core and wind cluster centre.

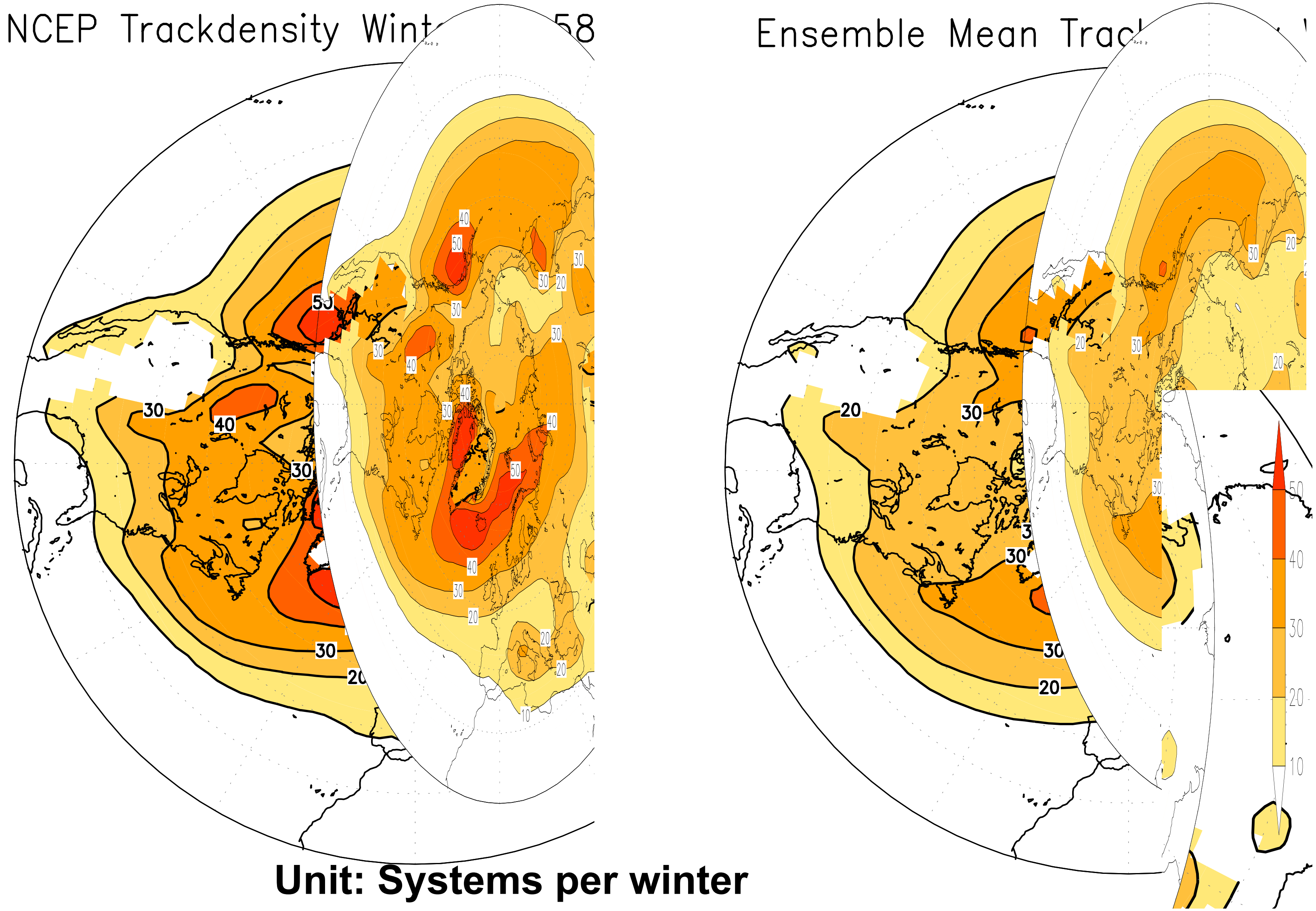
The total area with wind speeds exceeding the 98th percentile over the 2 day period is shown in gray.

Cyclone weak according to MSLP, 2 extreme wind areas

NCEP Re-analysis: Track density
48 Winter (ONDJFM), ALL Systems

Ensemble Mean: Track density
Winter (ONDJFM), ALL Systems

1958-2007



Unit: Systems per winter

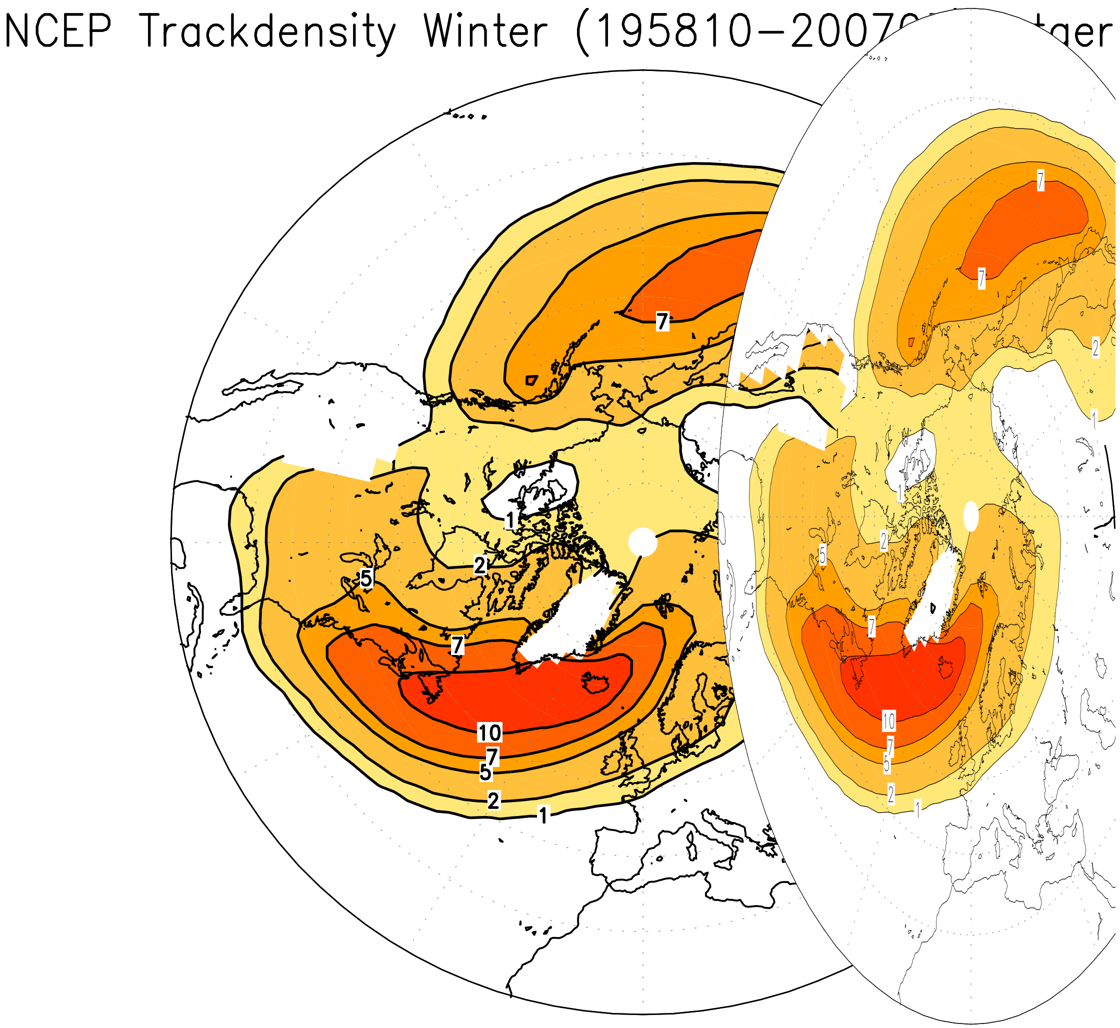
Definition: Extreme Cyclone Systems

Systems with a Laplacian of MSLP ($\nabla^2 p$) above the 95th percentile,

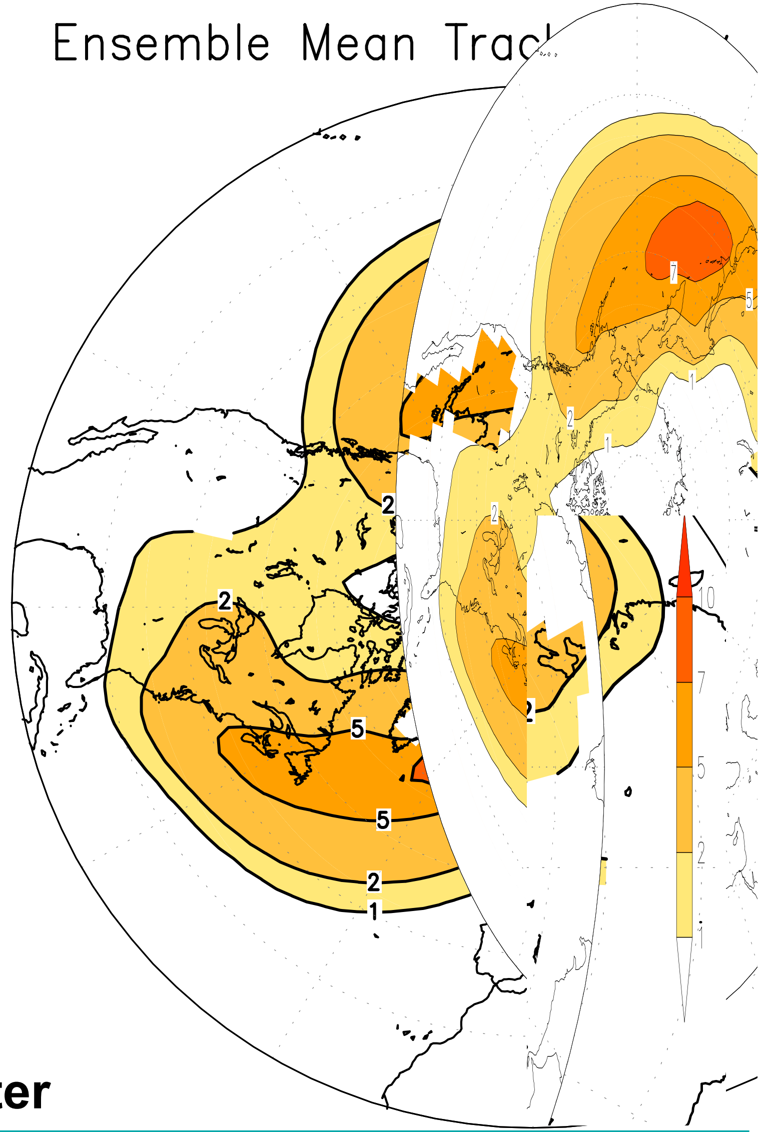
i.e. only the upper 5% of the distribution are recognised here

NCEP or ERA40 re-analysis:
most of the historical relevant winter storms are included (as far as storms are resolved by re-analysis data)

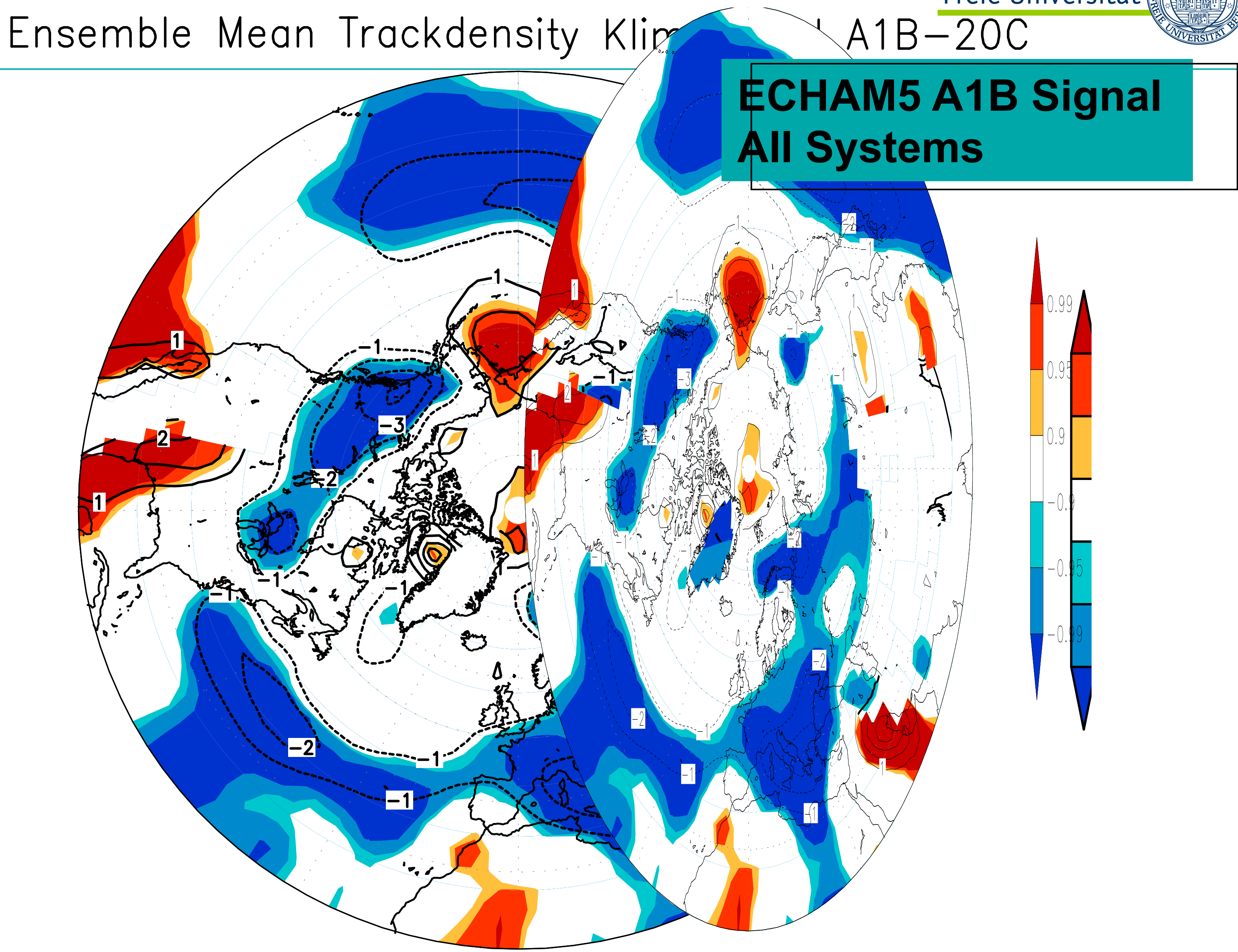
NCEP Re-analysis: Track density
48 Winter (ONDJFM), Strong Systems



Ensemble Mean: Track density
Winter (ONDJFM), Strong Systems



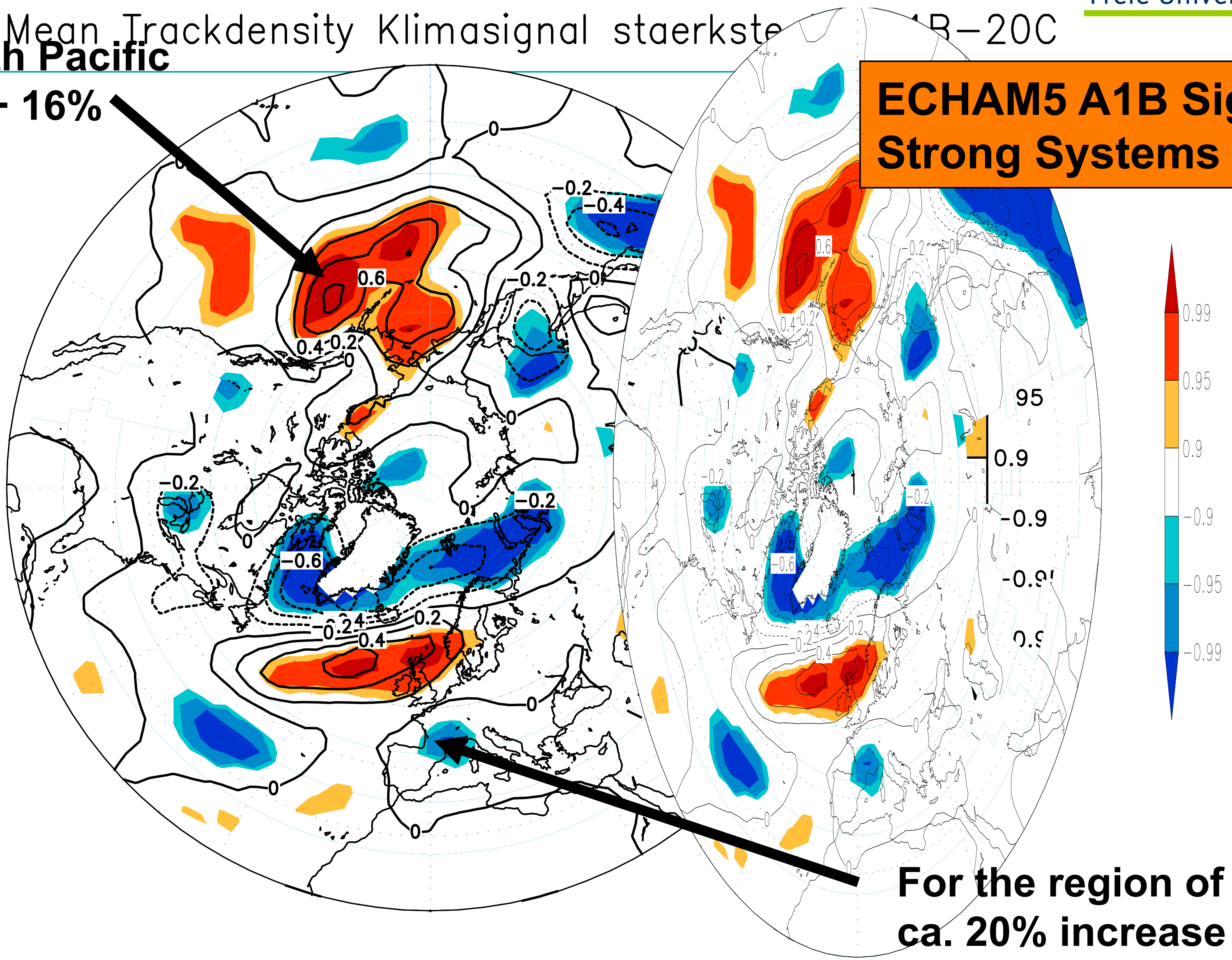
Unit: Systems per winter


Ensemble Mean Trackdensity Klim A1B−20C
ECHAM5 A1B Signal
All Systems
0.99
0.95
0.9
−0.9
−0.95
−0.99

Freie Universität Berlin

ECHAM5 A1B Signal Strong Systems

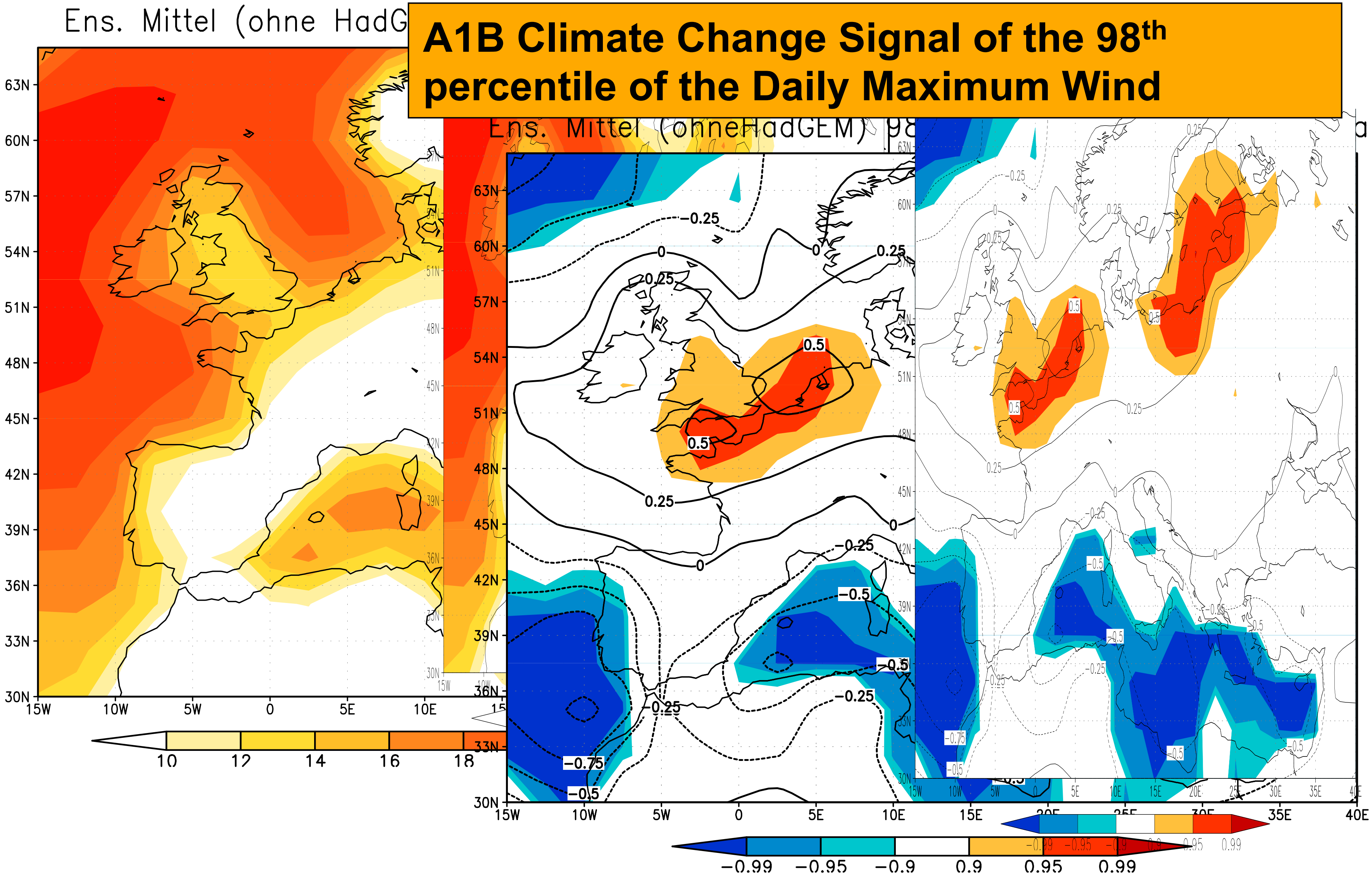
North Pacific
ca. + 16%



For the region of e.g. Scotland: ca. 20% increase

98th percentile of the Daily Maximum Wind

A1B Climate Change Signal of the 98th percentile of the Daily Maximum Wind



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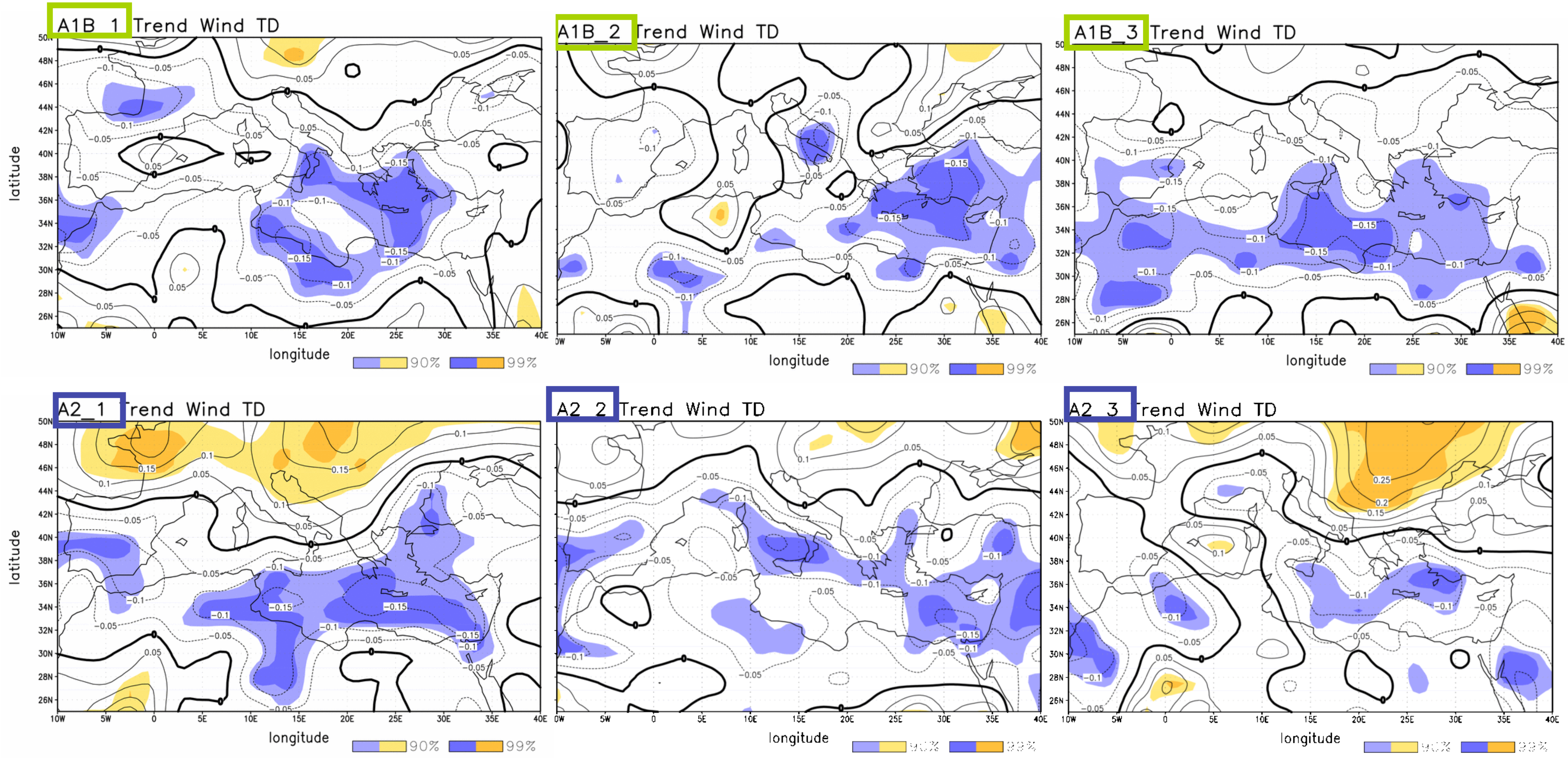
TRENDS IN WIND STORM FREQUENCY



Linear trends in wind track density 2001-2100
Units: wind events/10winter seasons/(deg.lat)^2

TRENDS IN STORM PRODUCING CYCLONE FREQUENCY

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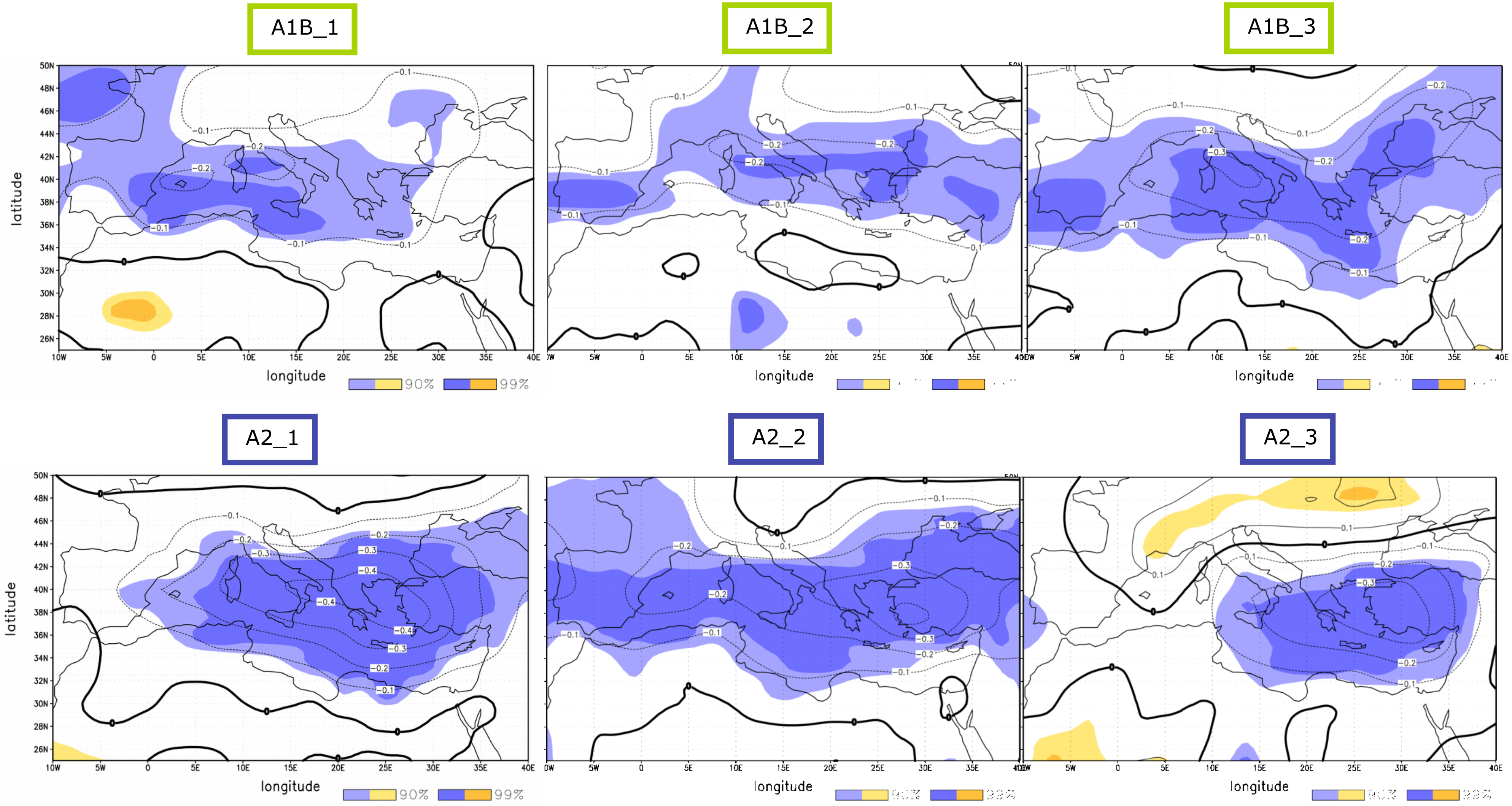

Linear trends in cyclone track density 2001-2100
Units: cyclones/10winter seasons/(deg.lat)^2