Satellite Based Climatology of (Sub-) Tropical Cyclones in Europe

Pieter Groenemeijer
Alois M. Holzer

“Do storms with tropical characteristics occur in the waters surrounding Europe?”

“If they occur, how often do they occur and how strong are they?”

Answers:

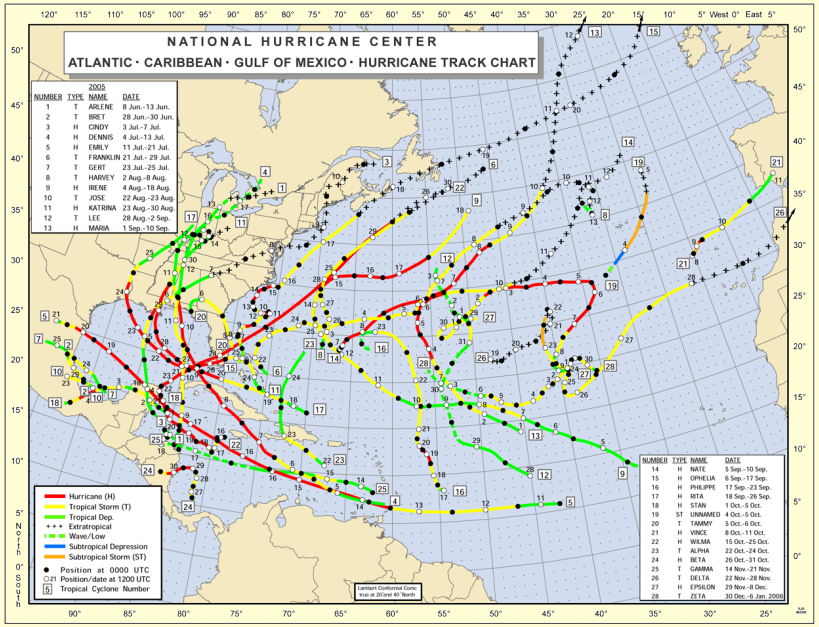
- Selected cases well-documented in scientific literature
- Speculations dominate sound facts in grey literature about intensity and frequency, first climatologies presented

We invented nothing new:

We just did what TC centers worldwide already do for decades - apply the Dvorak technique.

Goals

- Establish a **consistent climatology:**
  in time and
  with worldwide references
  for the waters surrounding Europe



NHC HTC 2005

- 6-hourly positions and maximum intensity
- Central feature characteristics
- Distinction between tropical, subtropical and extratropical nature and its stages

Methodology

Use established manual methods (Dvorak, Hebert and Poteat) together with recent additions (WMO definitions, Global Guide to Tropical Cyclone Forecasting - BOM) **for all historic cases of the available METEOSAT first generation archive** (1982 – 2006).

These methods (manual review of mainly IR and VIS imagery and data) are **in operational use for at least two decades**.

- Data of other oceanic basins was analysed with the same methods: **comparable dataset**
- **Independent** from other sources (like models - problems with sparse observational data and/or resolution of reanalyses)

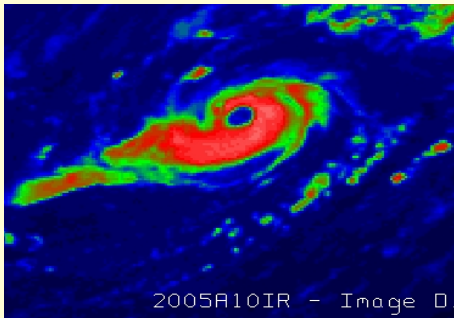
Basic Definitions

Tropical Cyclone

A **warm-core non-frontal synoptic- or meso-scale cyclone** with **organized deep convection** and a **closed surface wind circulation about a well-defined center**.

Nature	Extratropical	Subtropical			Tropical		
	Baroclinic Low	Hybrid System			Symmetric Deep Warm Core Low		
Max. sustained Wind							
	Remnant Low						
	Extratropical Low						
<< 34 kt					Tropical Disturbance, Zehr (1992) Stage 0: Pre-Genesis		
<< 34 kt					Tropical Disturbance, Zehr (1992) Stage 1: Suspect Area		
< 34 kt					Tropical Disturbance, Zehr (1992) Stage 2: Incipient Tropical Cyclone -> Start of Dvorak		LLCC and persistent convection
< 34 kt		Subtropical Depression	}	Subtropical Cyclone	Tropical Depression	}	
≥ 34 kt		Subtropcial Storm			Tropical Storm		Tropical Cyclone
≥ 64 kt					Intense Tropical Cyclone, Hurricane, Taiphoon, Cyclone and other regional names		

Definition sources: NOAA NHC and GGTCF



Hurricane Vince near Madeira, Oct. 2005

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< 34 kt					Tropical Disturbance
< 34 kt		Subtropical Depression	}	Subtropical Cyclone	Tropical Depression
≥ 34 kt		Subtropcial Storm			Tropical Storm
≥ 64 kt					Intense Tropical Cycl

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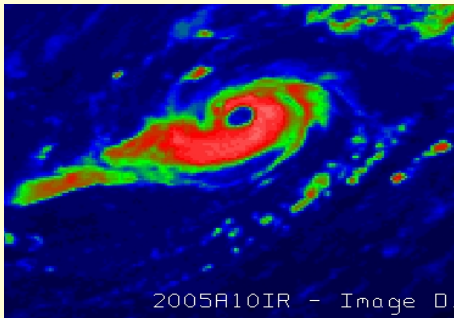

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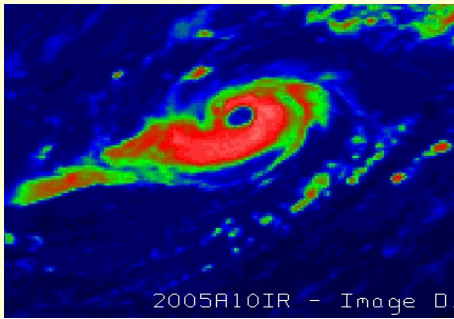

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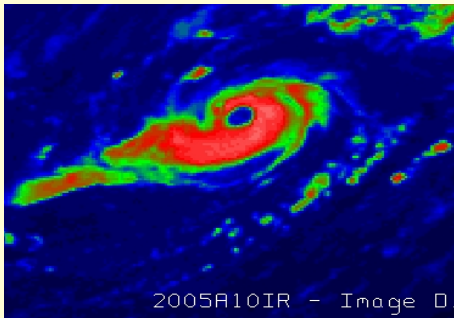
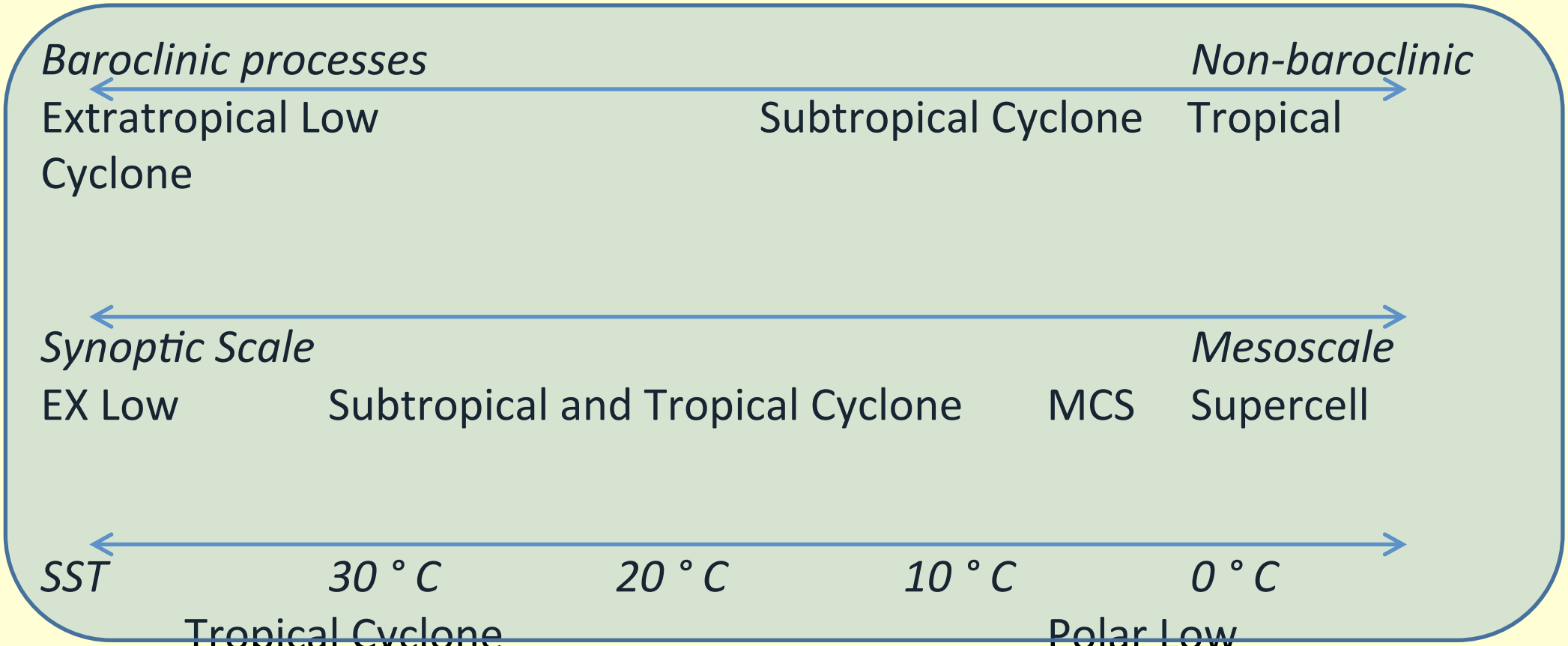


Hurricane Vince near Madeira, Oct. 2005

Basic Definitions

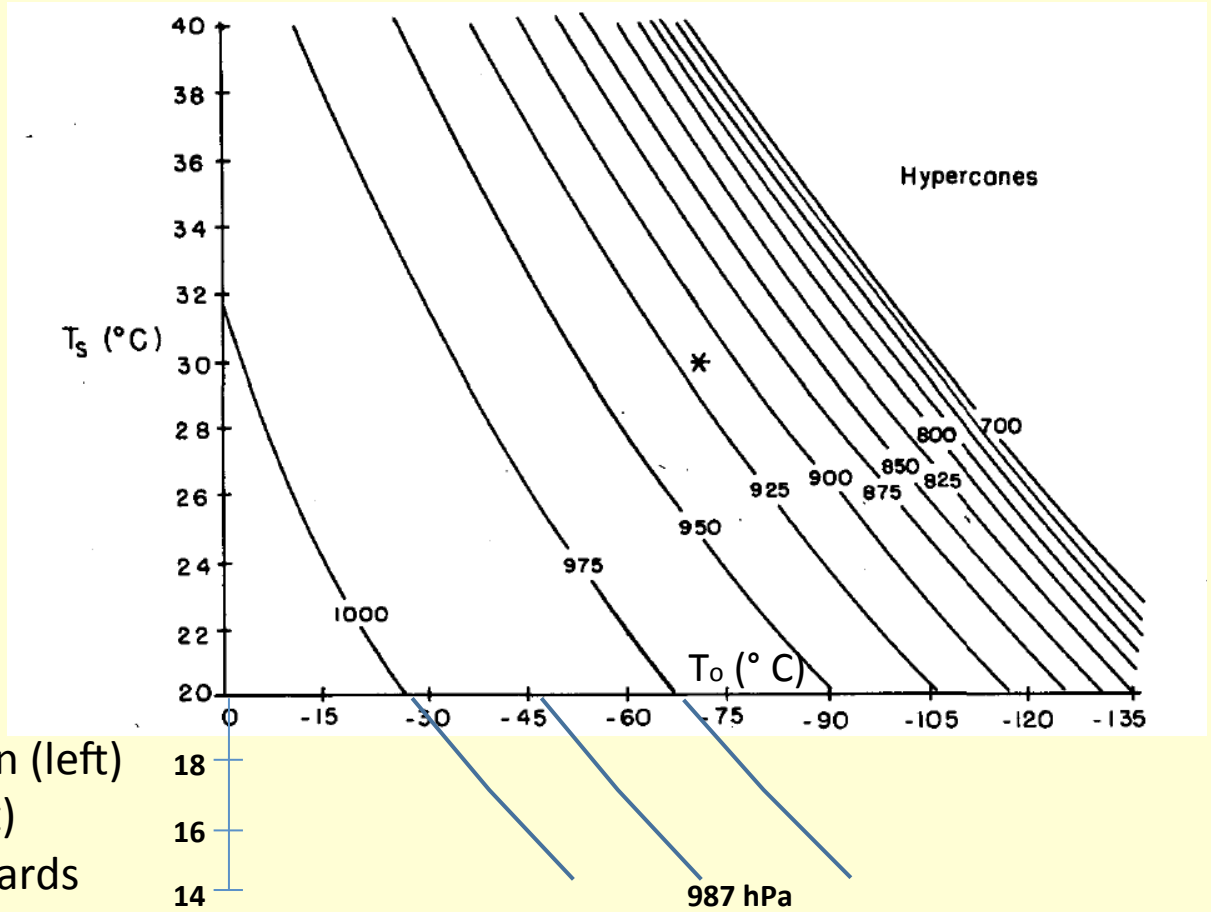
Nature is „playful enough“ to produce a **continuum of phenomena**, but we are eager to pack those phenomena into clearly distinguishable boxes: scales, energy sources, …



Basic Thoughts

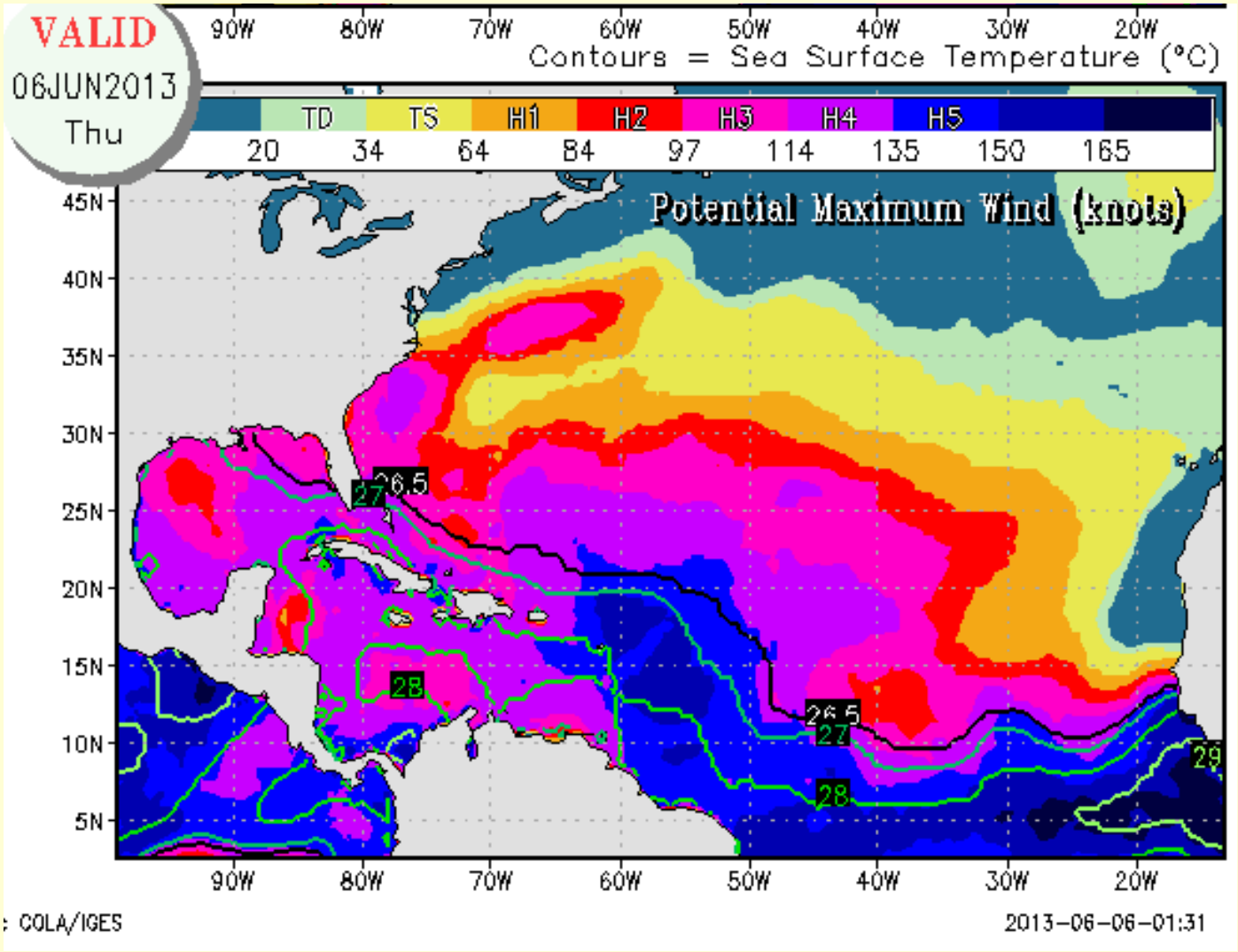
Is there a "**magic" threshold of 27 ° C SST for tropical cyclone formation?**
No, but the current theory provides relations to SST (ordinate of diagram), outflow temperature (abszissa of diagram) and outside MSLP:

CI Number	MWS (Knots)	MWS (MPH)	MSLP (Atlantic)
1	25 KTS	29 MPH	
1.5	25 KTS	29 MPH	
2	30 KTS	35 MPH	1009 mb
2.5	35 KTS	40 MPH	1005 mb
3	45 KTS	52 MPH	1000 mb
3.5	55 KTS	63 MPH	994 mb
4	65 KTS	75 MPH	987 mb
4.5	77 KTS	89 MPH	979 mb
5	90 KTS	104 MPH	970 mb
5.5	102 KTS	117 MPH	960 mb
6	115 KTS	132 MPH	948 mb
6.5	127 KTS	146 MPH	935 mb
7	140 KTS	161 MPH	921 mb
7.5	155 KTS	178 MPH	906 mb
8	170 KTS	196 MPH	890 mb



Dvorak CI-MWS-MSLP empirical relation (left) and Maximum Potential Intensity (right) from Emanuel (1988) extrapolated towards lower SSTs (based on 1013 hPa environmental pressure and 80 % relative humidity)

Maximum Potential Intensity



Recent maps of maximum potential intensity from webpage of Kerry Emanuel (http://wxmaps.org/pix/hurpot.html#ATL)

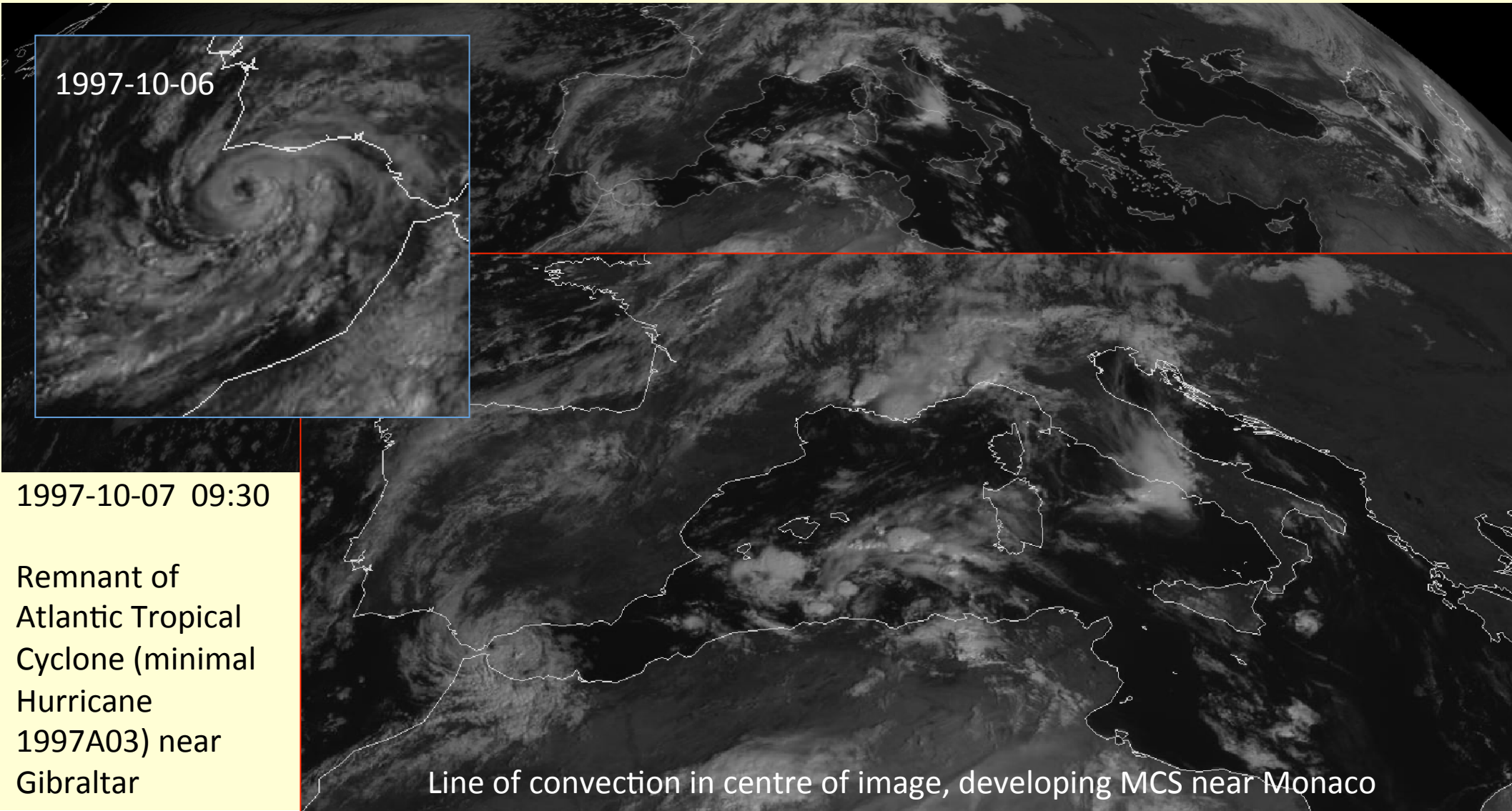
Research Method

STEP 1

- **Manual review of 3-hourly METEOSAT first generation IR and VIS imagery** of the years 1982 to 2006
- Those are **121 723 files**.
- The human eye is quite good in catching organized high-contrast clusters and bands of deep convection, especially when pictures „run“ by repeated clicking of the „next button“.

„Look, there is a snail on your computer!“ © Emma Holzer, 4 years old

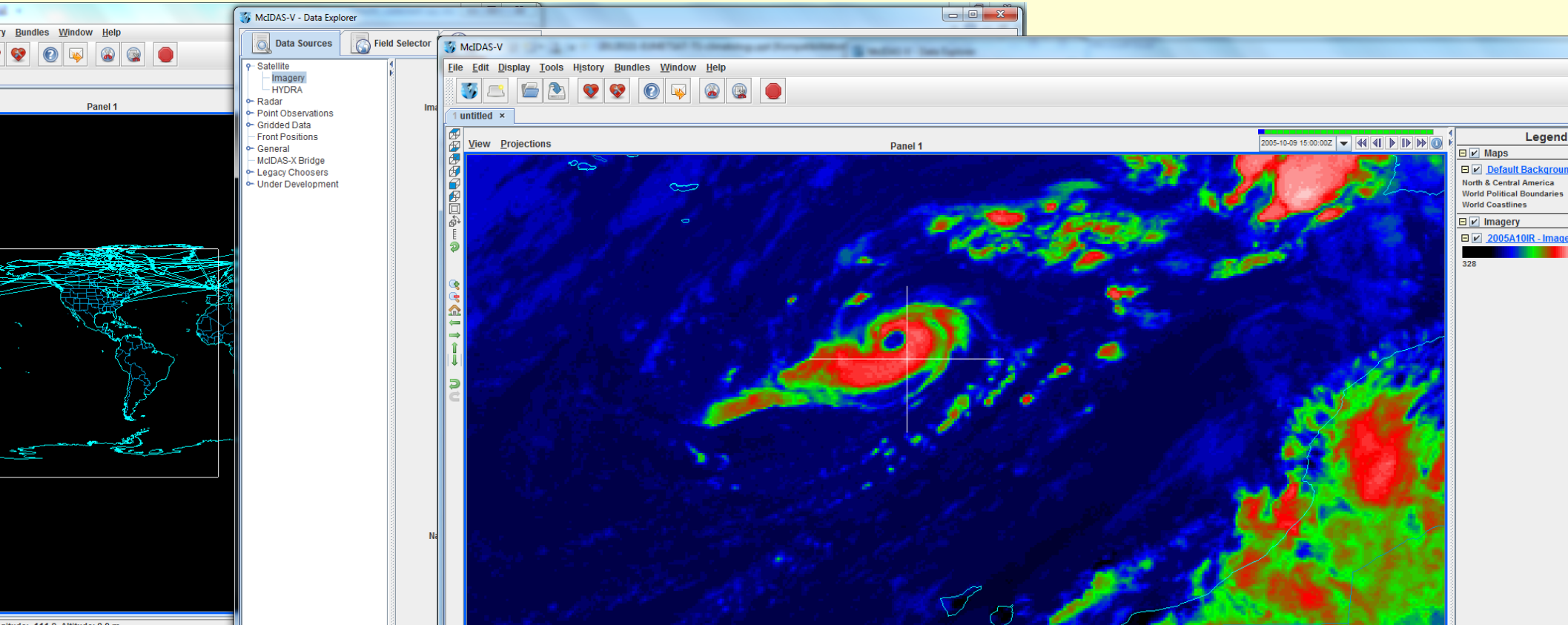
Research Method – STEP 1



Research Method

STEP 2

- Detailed analyses of the data in suspect timeframes (IR, VIS and WV) with MCIDAS



'EIR' ANALYSIS DIAGRAM

Vernon F. Dvorak (April 1984)

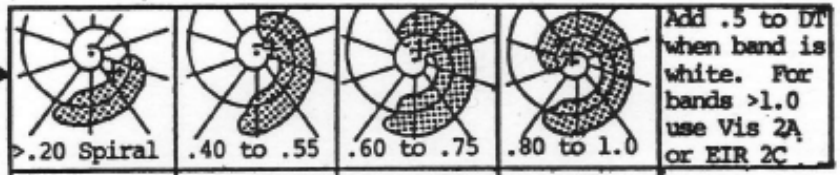
1. START
Locate cloud system center.

Locate the "CSC" at the focal point of all the curved cloud lines or bands. For initial development (T1), see Step 1A.

2. Analyze using pattern below when possible; then go to Step 3.

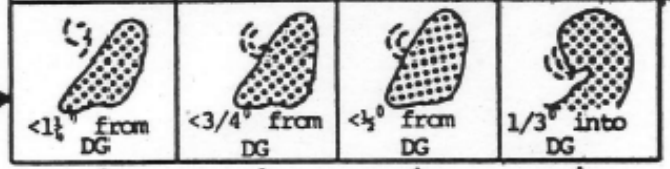
When your storm pattern does not fit the description of any of Steps 2A thru E, do Steps 3, 4, 5, and 6; then return to Step 2 if indicated.

2A "Curved Band" Pattern (Use spiral arc distance along 10° log spiral).



Add .5 to DT when band is white. For bands >1.0 use Vis 2A or EIR 2C.

2B "Shear" Pattern
Use center definition and center's distance to dense overcast.



DT1.5±.5 | DT2.5 | DT3 | DT3.5

2C "Eye" Pattern

Was 24-hr old T-no. ≥T2?

YES

Narrowest Width	≥.5	≥.5	≥.5	≥.4	≥.4	≥.3	≥.3
Surrounding Gray Shade	CMG	W	B	LG	MG	DG	OW
	E6.5	E6	E5.5	E5	E4.5	E4.5	E4

NO → Step 2A or 4

2E "Embedded Center" Pattern (Center within cold ⊕ by ≥0.4.)

Was 12-hr old T-no. ≥T3.5?

YES

Embedded Distance	≥.6	≥.6	≥.5	≥.5	≥.4	≥.4
Surrounding Gray Shade	White or Colder	B	LG	MG	DG	OW
	CF5	CF5	CF4.5	CF4	CF4	CF3.5

NO → Step 2A or 4

GRAY SHADE CODE (BD CURVE)

WMG	(Warm Medium Gray),	> +9°C
OW	(Off White),	+9 to -30°C
DG	(Dark Gray),	-31 to -41°C
MG	(Medium Gray),	-42 to -53°C
LG	(Light Gray),	-54 to -63°C
B	(Black)	-64 to -69°C
W	(White)	-70 to -75°C
CMG	(Cold Medium Gray),	-76 to -80°
CDG	(Cold Dark Gray),	≤ -81°C

EYE TEMPERATURE

SURR. RING TEMP. \	WMG	OW	DG	MG	LG	B	W
OW	0	-0.5					
DG	0	0	-0.5				
MG	0	0	-0.5	-0.5			
LG	+0.5	0	0	-0.5	-0.5		
B	+1.0	+0.5	0	0	-0.5	-0.5	
W	+1.0	+0.5	+0.5	0	0	-1.0	-1.0
CMG	+1.0	+0.5	+0.5	0	0	-0.5	-1.0

Eye Adjustment? E-no. + Eye Adj = CF

Banding Feature (BF)? CF + BF = DT

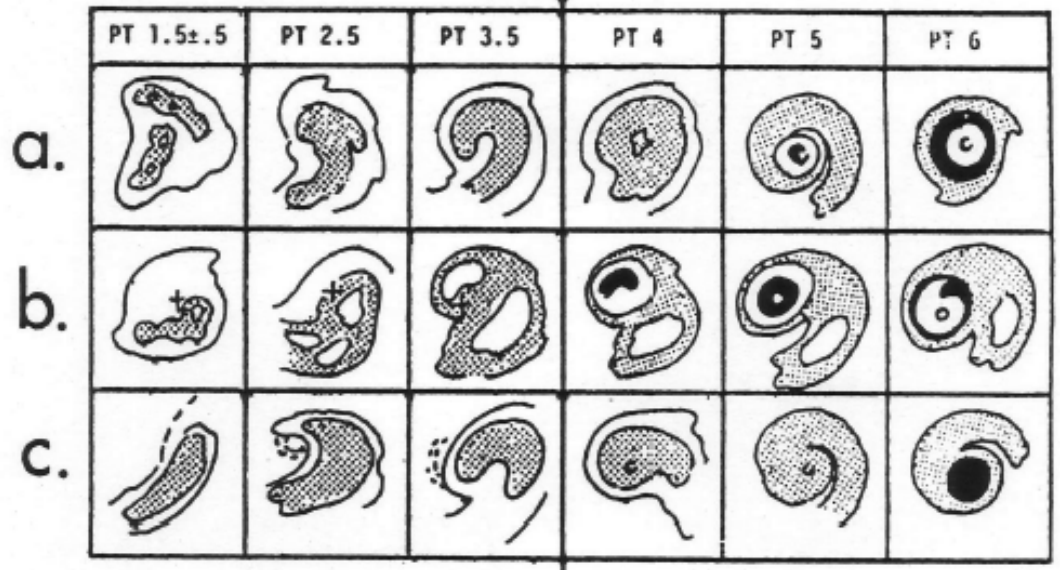
3. "Central Cold Cover" Pattern

Rules: When past T-no. ≤T3, maintain model trend for 12 hours; then hold same. When past T-no. ≥T3.5 hold T-no. same. Use as final T-no.; then go to Step 9.

4. Determine past 24-hour trend. Is Development, Weakening, or Same indicated in a change of:
(a) center or eye characteristics, or
(b) center's involvement with the cold overcast.

5. Determine Model Expected T-no. (MET).

6. Determine pattern T-no. Select pattern in diagram that best matches your storm picture within one column of the MET. Adjust MET ± .5 when indicated.



*When hatched part of these patterns is white or colder, add .5 to pattern number.

7. T-no. Determination:

1. Use data T-no. from Step 2 when cloud features are clear-cut.
2. Use Pattern T-no. when DT is not clear and adjustment to MET is made.
3. For all other cases, use the MET.

8. Final T-number Constraints:

1. Initial classification must be T1 or T1.5.
2. During first 48 hours of development, T-no. cannot be lowered at night.
3. 24 hrs after initial T1, storm's T-no. must be <T2.5.
4. Final T-no. limits: <T4: change of 1/2 over 6 hrs. >T4: change of 1 over 6 hrs, T.5 over 12 hrs, 2 over 18 hrs, and 2.5 over 24 hrs.
5. Final T-no. must = MET ±1.

9. Current Intensity (CI) Number Rules:

1. Use CI = final T-no. except when final T-no. shows change to weakening trend, or when redevelopment is indicated.
2. For initial weakening, hold CI same for 12 hours, then hold CI ½ or 1 higher than T-no. as storm weakens.

10. 24-Hr Forecast:

Extrapolate past trend unless one of the five rules in the instructions applies.

TD (max 2,0)

TROPICAL CYCLONE ANALYSIS WORKSHEET

Vernon F. Dvorak
June 1983

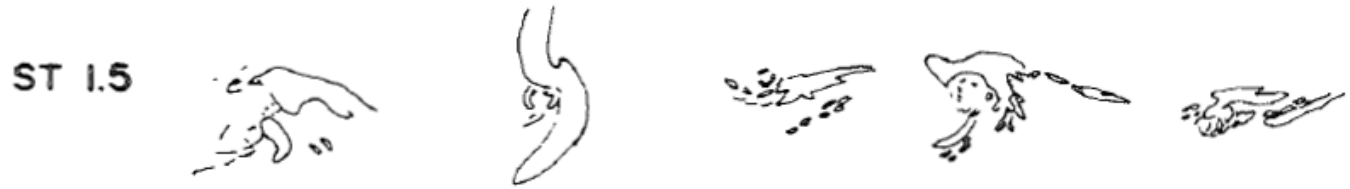
T-NUMBER ESTIMATE FROM MEASUREMENTS FOR DATA T-NUMBER (DT) COMPUTATION

T-NUMBER ESTIMATE FROM MODEL (AND DT CONSTRAINTS)

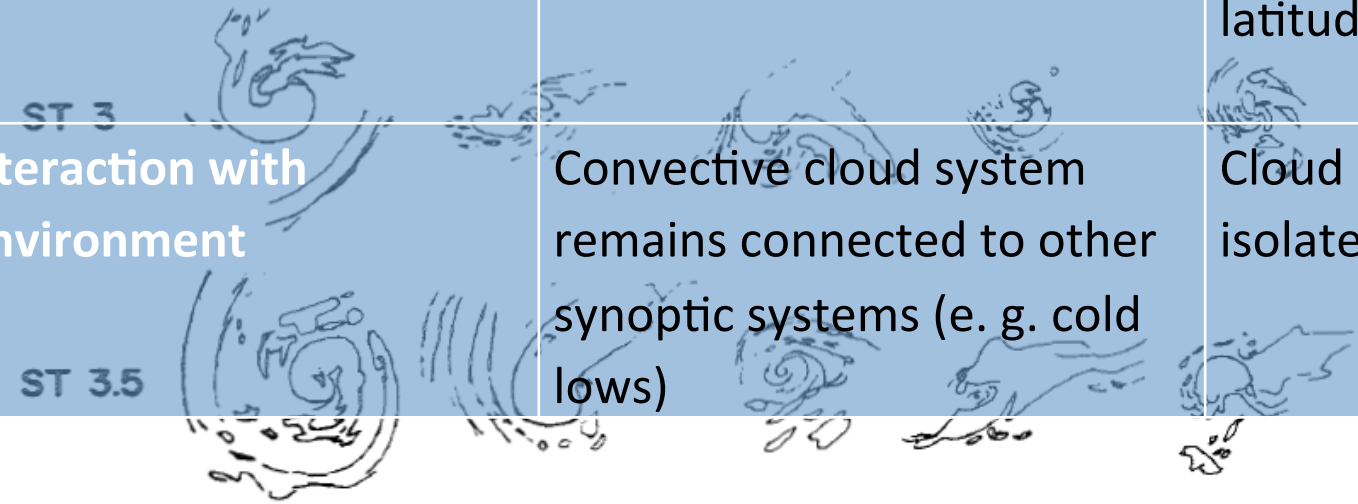
STEP –	1		2A,B				2C				2D	2E	Data T-Number Computation			3	4	5	6	7,8	9	10		
DESCRIPTION –	Location		Curved Band or Shear				Eye		$E_{No}+E_{Adj}=CF$		CDO	Emb. Centr.				CCC	Trend	MET	PAT	FT	CI	24-Hr. Fcst.		
RULES – 2005M01	Locate Cloud System Center at focal point of cloud curvature		Use Spiral Arc Length				(VIS) Use Embedded Distance	(EIR) Use Surrounding Temperature	From Rules	Eye Definition	Use Size	(EIR) Use Surrounding Temperature	CF+BF=DT			Use Rules	24-Hr change	Model Expected T-Number	Pattern T-Number	Use Rules		Adj. Model Fcst. if nec.		
DATE/TIME	LAT	LONG	DT 1.5	DT 2.5	DT 3.5	DT 4.5			E_{No}	E_{Adj}	Central Dense Overcast		CF	BF	DT	Central Cold Cover	D-developing W-weakening S-same			Final T-Number	Current Intensity Number	List Rule Used	Forecast Intensity Number	INITIALS
25.10. 12^{00}	36,6	17,2	increasing conv. over LLCC																					ST1
18^{00}	36,8	17,3	– " –																					ST2
26.10. 0^{00}	37,0	17,2	– " –																					ST2
06^{00}	37,3	16,9	deep persistent conv. over LLCC																					ST2
12^{00}	37,8	17,4	– " –																					ST2
18^{00}	38,0	17,6	– " –																					ST2
27.10. 0^{00}	37,0	16,7	– " –																					ST2
06^{00}	36,9	16,5	x												1,5					1,5	1,5			TD initial CI
12^{00}	36,7	16,1		x											2,5					2,0	2,0			TD
18^{00}	36,3	16,0	diminishing deep conv.															2,0		2,0	2,0			TD
28.10. 0^{00}	36,2	16,4	no deep conv.															1,5		1,5	1,5			TD
06^{00}	35,4	16,8	no deep conv. for nearly 12 hrs.															1,0		1,0	1,0			RL
12^{00}	34,7	17,4																			1,0			RL
18^{00}	33,9	18,1																			1,0			RL
29.10. 0^{00}	33,0	18,7																			1,0			RL
06^{00}	32,4	19,1	deep conv. re-developing																		1,0			RL
12^{00}	31,9	19,3	banding structures re-developing												1,5					1,5	1,5			TD
18^{00}	31,5	20,5																			1,0			TD landfall
30.10. 0^{00}	30,8	21,9																						RL

Research Method

Distinction between tropical and subtropical type of cyclone according to Hebert and Poteat (1975): pattern recognition



Determining Type	Subtropical	Tropical
1. Main convection	Poleward and eastward from center	Equatorward and eastward from center
1. Cloud system size	Width 15° latitude or more	Width usually less than 10° latitude
1. Interaction with environment	Convective cloud system remains connected to other synoptic systems (e. g. cold lows)	Cloud system becomes isolated



Research Method

STEP 3

Digitalization of 6-hourly „best track data“ (international standard), containing:

- Storm ID
- Date and time in UTC
- Geographical coordinates
- Storm intensity (Dvorak CI –no. or ST-no.)
- Storm classification
  TDi, TD, TS, TC or HUR,
  SDi, SD, SS, RL and EX

1998A04	11.18.1998 6:00	35,0	-16,0	1,5	TD
1998A04	11.18.1998 12:00	34,1	-17,4	1,0	TD
1998A04	11.18.1998 18:00	33,5	-19,0	1,0	TD
1998A04	11.19.1998 0:00	32,9	-20,3	1,0	TD
1998A04	11.19.1998 6:00	31,8	-22,1	1,0	TD
1998A04	11.19.1998 12:00	31,7	-22,8	1,0	TD
1998A04	11.19.1998 18:00	31,7	-23,4	1,0	TD
1998A04	11.20.1998 0:00	31,8	-24,2	1,0	TD
1998A04	11.20.1998 6:00	32,4	-25,5	1,0	TD
1998A04	11.20.1998 12:00	32,9	-26,4	1,0	TD
1998A04	11.20.1998 18:00	33,7	-26,5	1,0	TD
1998A04	11.21.1998 0:00	33,9	-26,4	1,5	TD
1998A04	11.21.1998 6:00	35,0	-26,1	2,0	TD
1998A04	11.21.1998 12:00	35,8	-25,4	2,0	TD
1998A04	11.21.1998 18:00	36,9	-24,7	1,5	TD
1998A04	11.22.1998 0:00	36,9	-23,6	1,5	TD
1998A04	11.22.1998 6:00	36,7	-22,5	1,5	TD
1998A04	11.22.1998 12:00	35,5	-22,2	1,0	TD
1998A04	11.22.1998 18:00	33,7	-22,9	1,0	TD
1998A04	11.23.1998 0:00	32,0	-23,7	1,5	TD
1998A04	11.23.1998 6:00	31,1	-25,6	1,5	TD
1998A04	11.23.1998 12:00	30,1	-27,4	1,5	TD
1998A04	11.23.1998 18:00	28,9	-29,1	1,5	TD
1998A04	11.24.1998 0:00	27,9	-29,6	1,5	TD
1998A04	11.24.1998 6:00	27,2	-30,5	2,0	TD
1998A04	11.24.1998 12:00	26,6	-31,4	2,5	TS
1998A04	11.24.1998 18:00	26,0	-32,3	2,5	TS
1998A04	11.25.1998 0:00	24,7	-33,2	3,0	TS
1998A04	11.25.1998 6:00	24,0	-34,0	3,0	TS
1998A04	11.25.1998 12:00	23,3	-35,2	2,5	TS
1998A04	11.25.1998 18:00	22,7	-35,8	2,0	TD
1998A04	11.26.1998 0:00	22,3	-36,1	1,5	TD

Research Method

STEP 4
Data plotting and statistics

Basin	Suspect cases analyzed	Subtropical and tropical cyclones found (depressions, storms, hurricanes)
Black Sea	**11**	**4**
Mediterranean Sea	**81**	**47**
Atlantic Ocean (see area definition)	**69**	**41**
Total	**161**	**92**

Roughly half of the suspect cases finally were classified as cyclones.
Constraints: LLCC, minimum lifetime of 24 hours, definitions as shown.

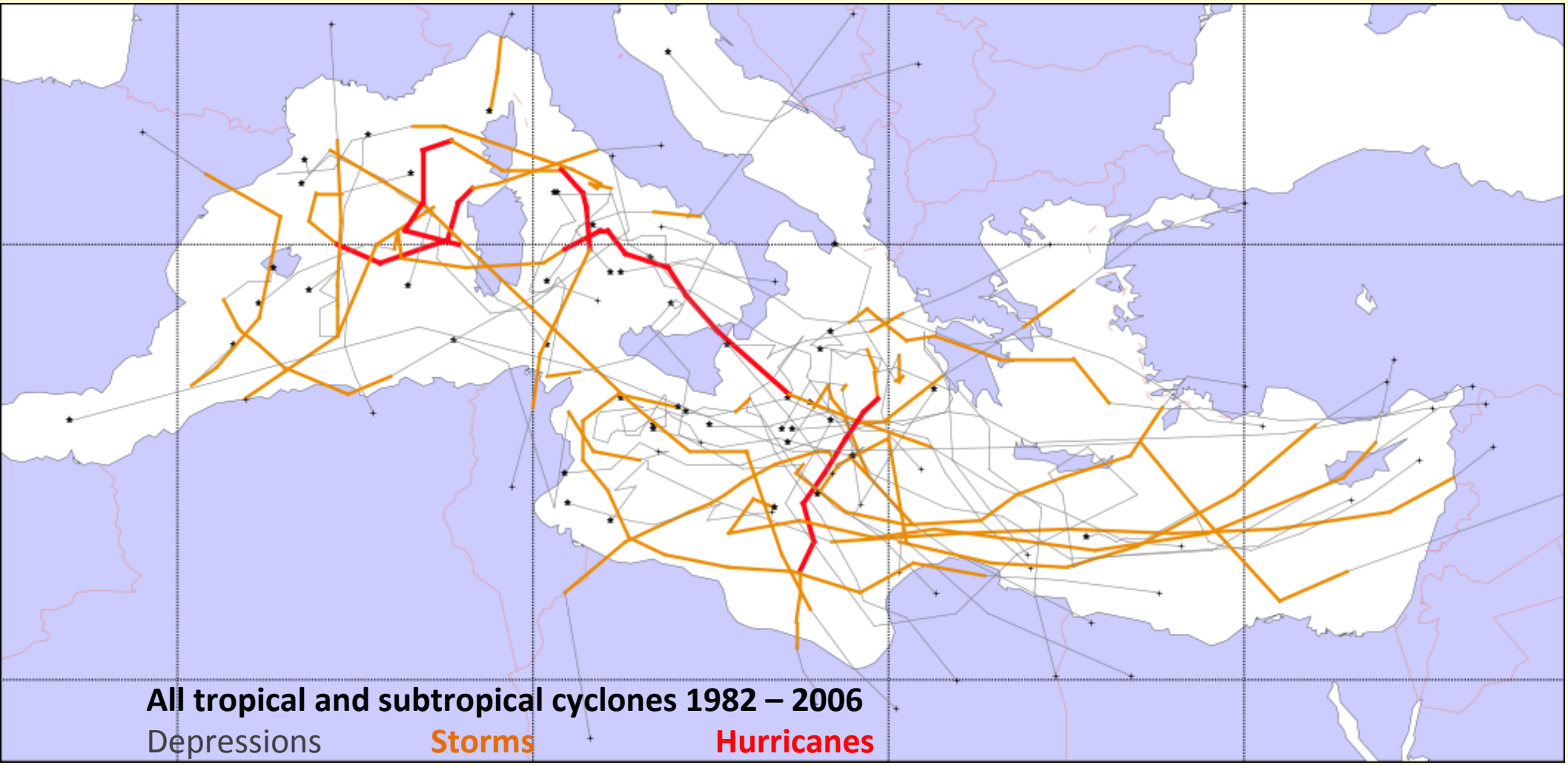
Results
Mediterranean Sea

	SDi	SD	SS	TDi	TD	TS	HUR
Total	14	3	18	16	13	9	4
SCs and TCs		21			26		
Storms to name		18				13	
Total storms to name: 31 (on average 1,3 per year)							

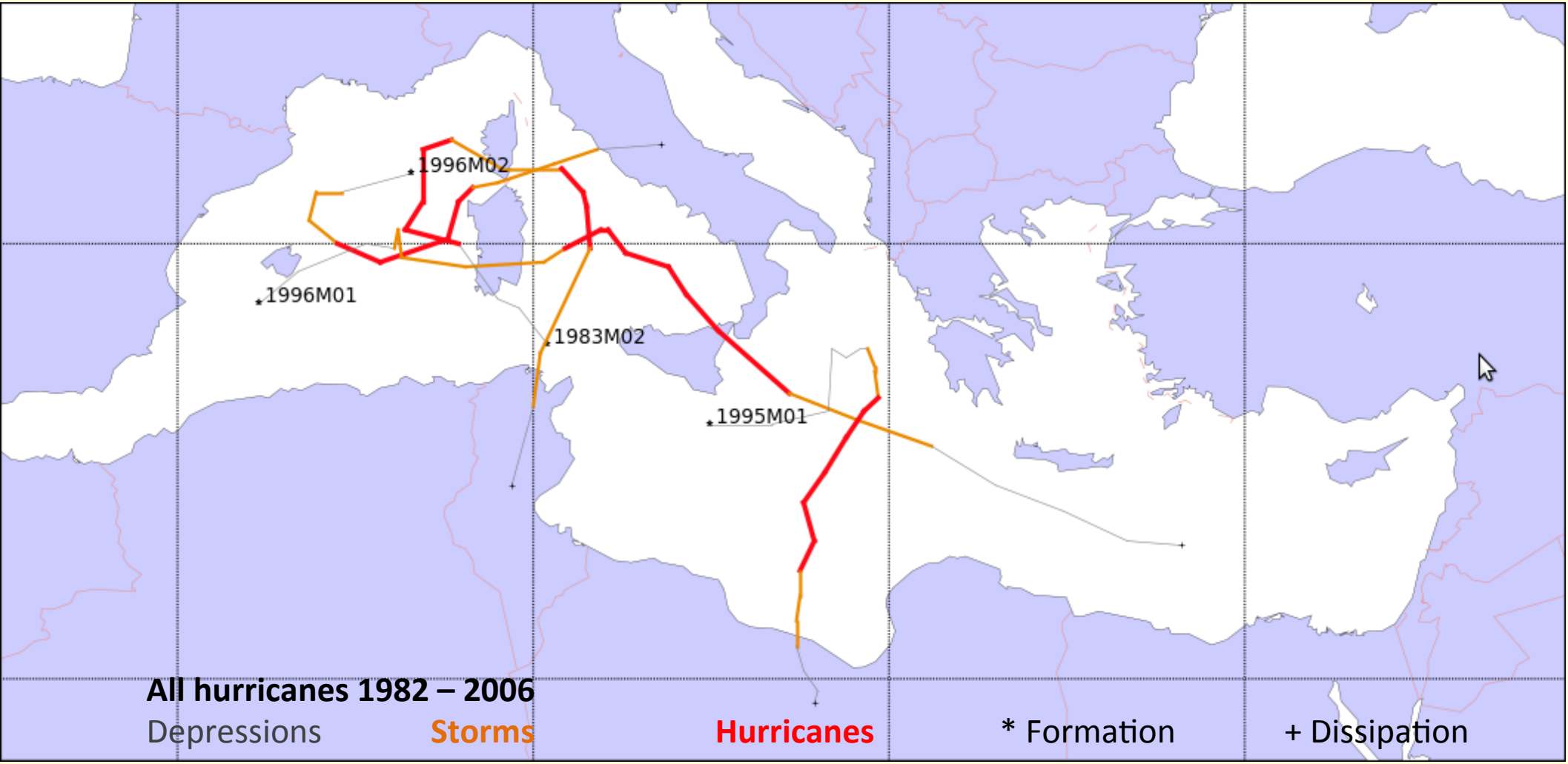
24 full years of imagery and/or data.

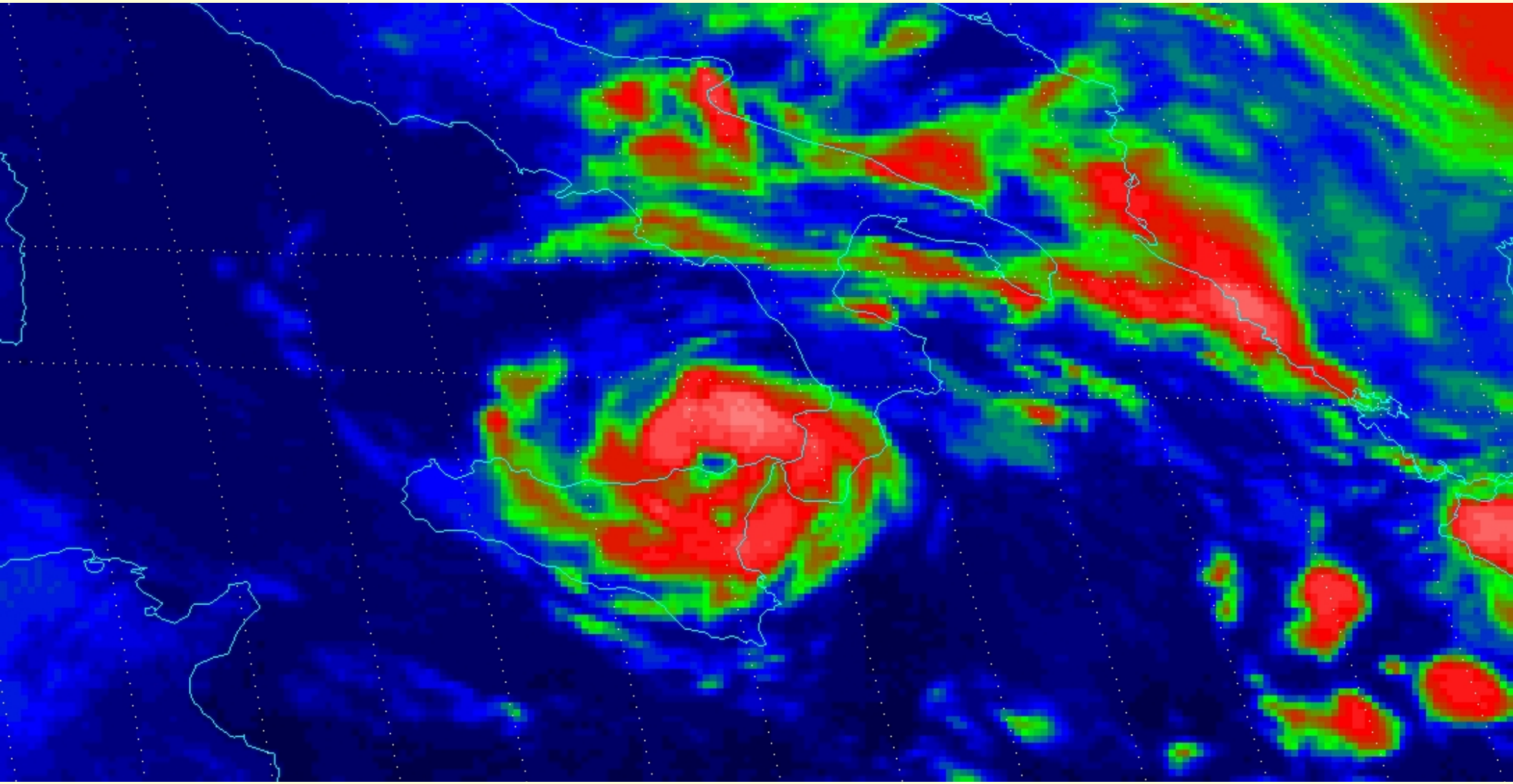
Critical periods of missing data: estimated with < 10 % (mainly in the early years)
Missing periods recorded for later reference.

Results
Mediterranean Sea



Results
Mediterranean Sea



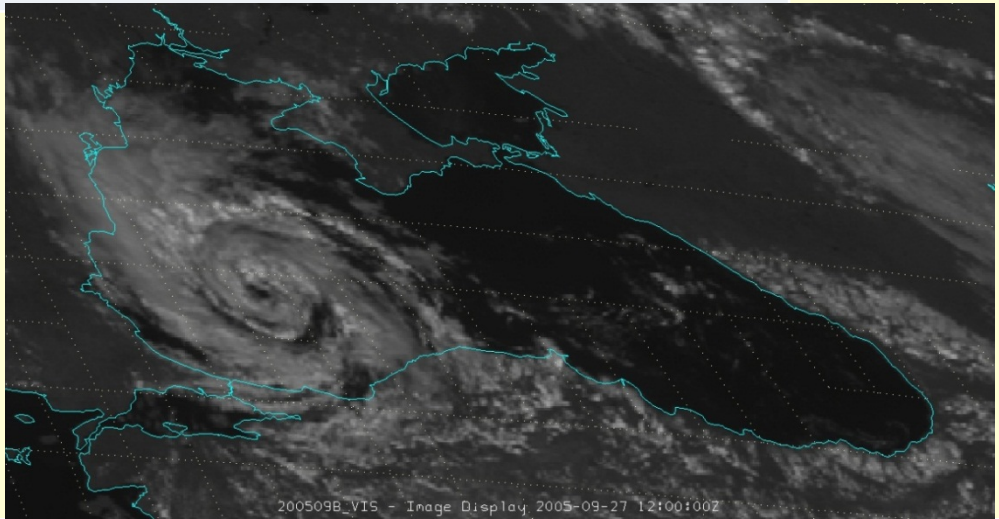


Hurricane 1996M01 at landfall in Sicily (midnight 9-10 Oct. 1996)

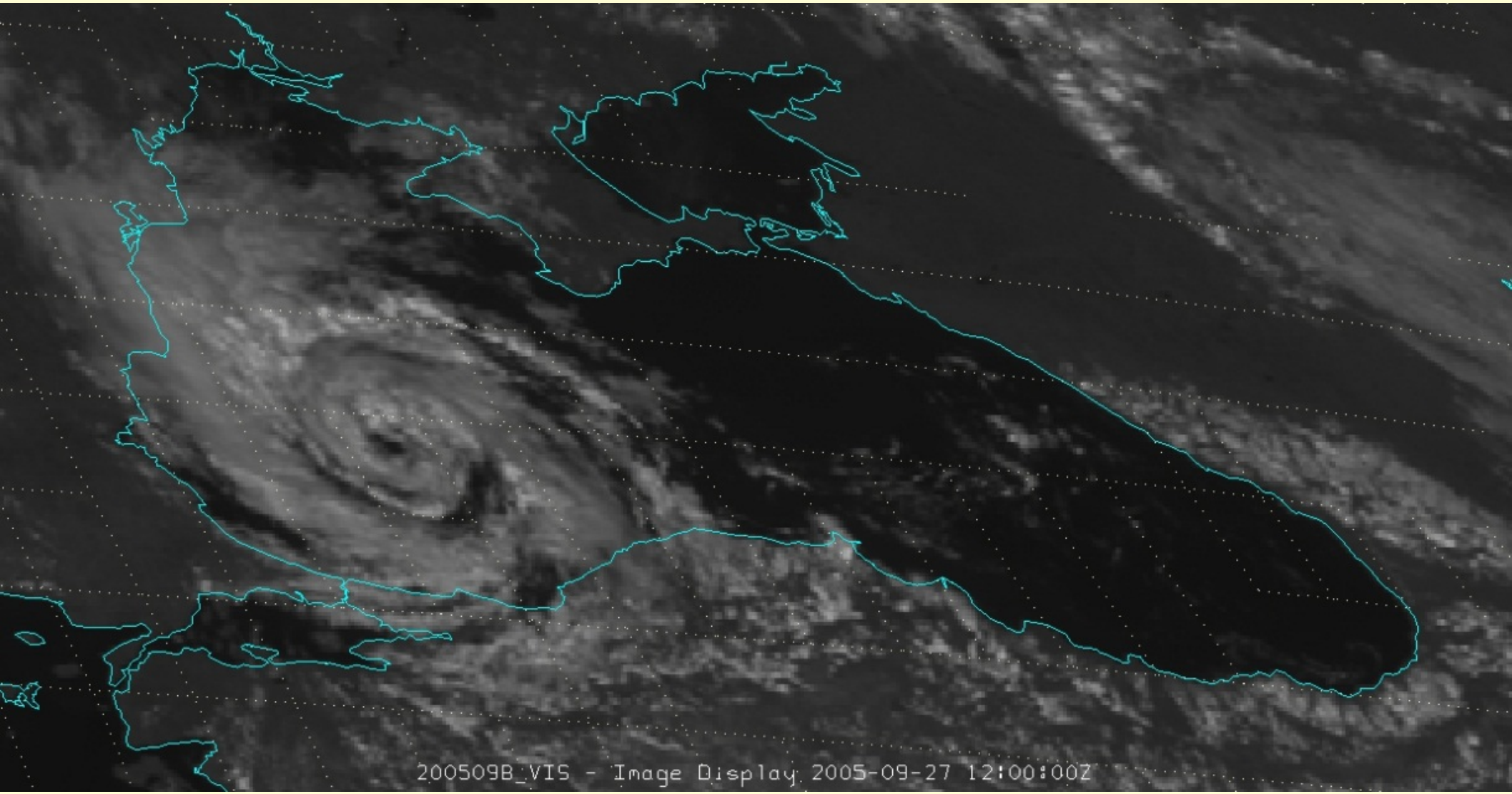
Results
Black Sea

Black Sea	SDi	SD	SS	TDi	TD	TS	HUR
Total			1	1	2	1	
SCs and TCs		1			3		
Storms to name		1				1	

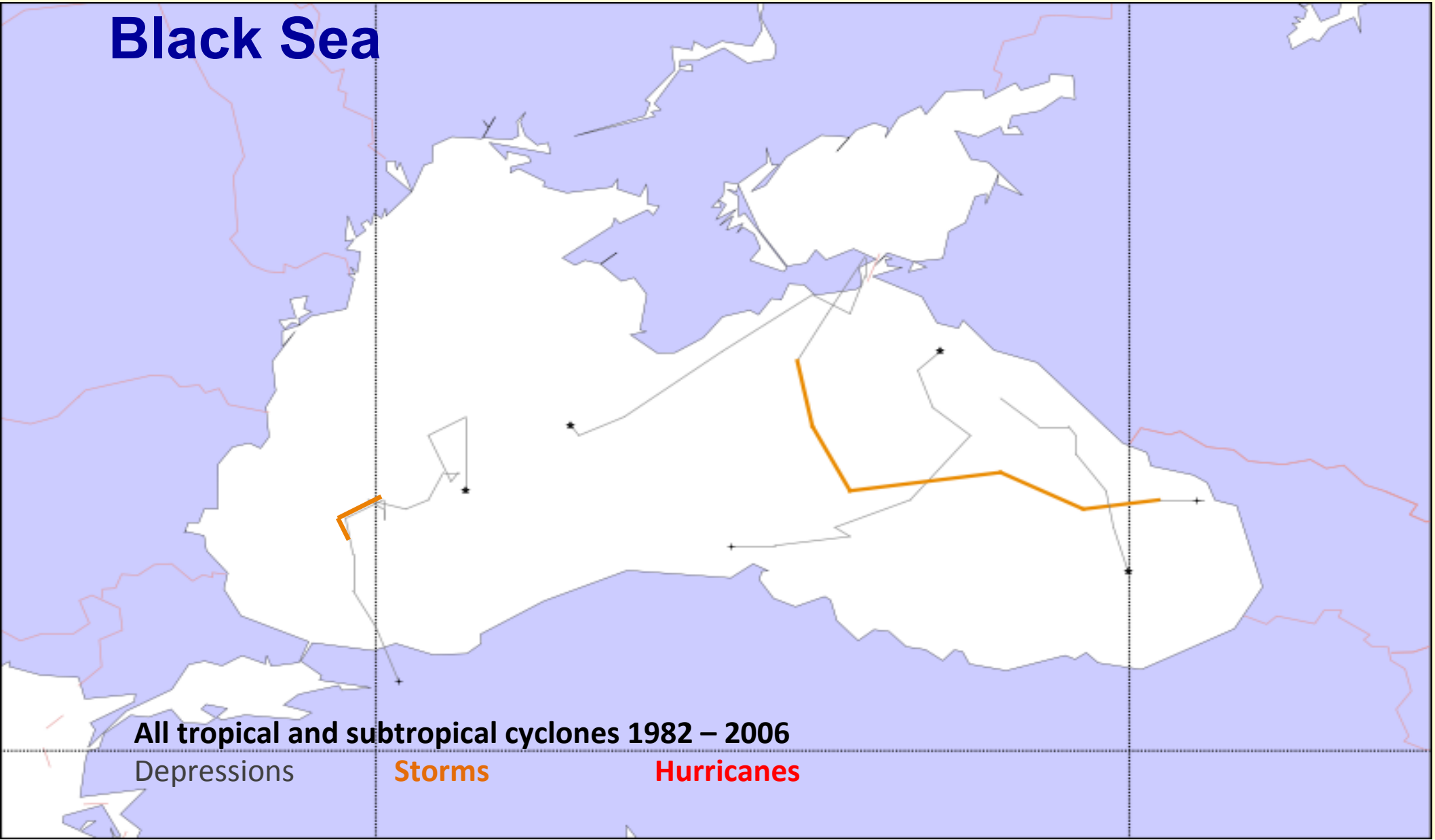
Total storms to name: 2 (on average 0,1 per year)



Results
Black Sea

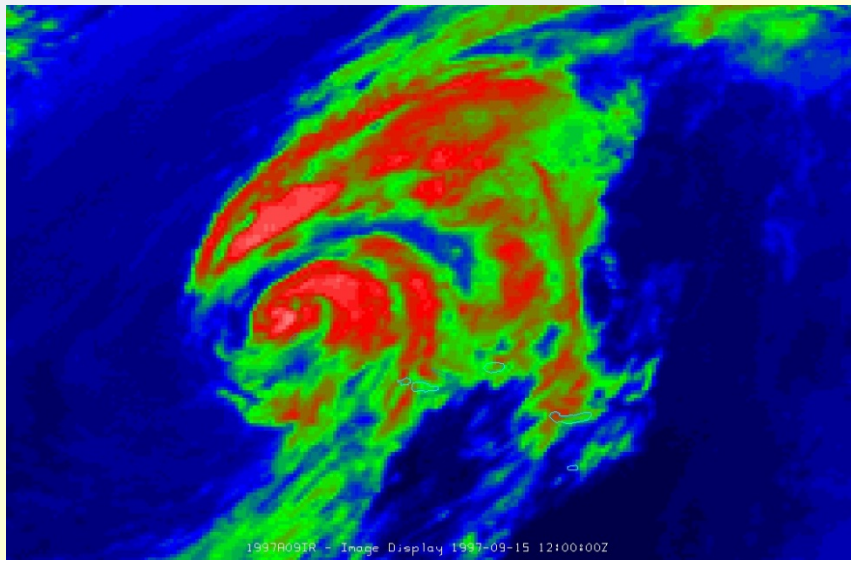


Results
Black Sea



Results
Atlantic Ocean (study area)

Atlantic Ocean	SDi	SD	SS	TDi	TD	TS	HUR
Total	1	2	12	1	3	19	5
SCs and TCs		14			27		
Storms to name		12				24	
Total storms to name: 36 (on average 1,5 per year)							



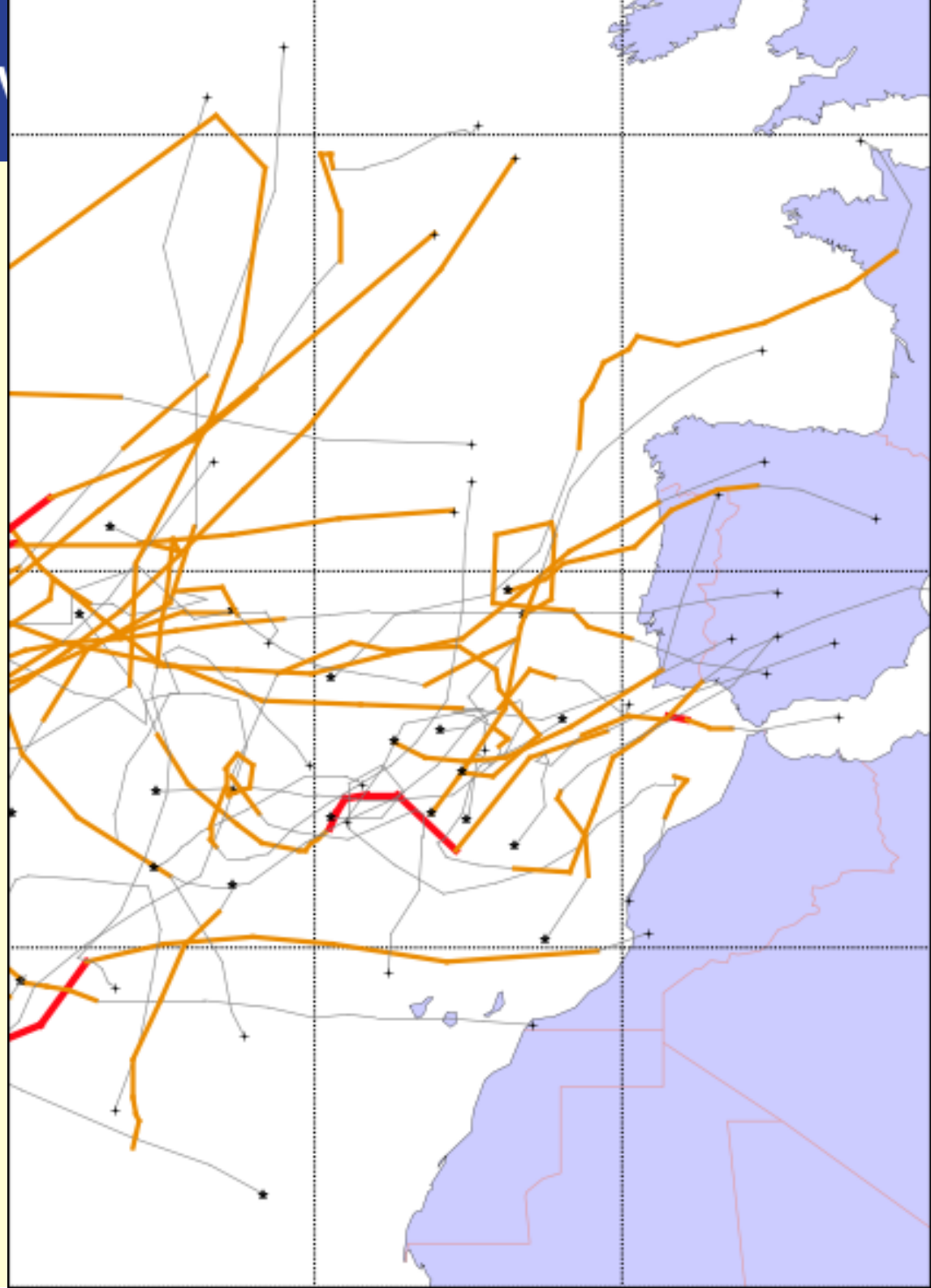
TS on 15 Sept. 1997 (NHC Erika)

ESSL European Se

Results
Atlantic Ocean

All tropical and subtropical cyclones
1982 – 2006

Depressions
Storms
Hurricanes

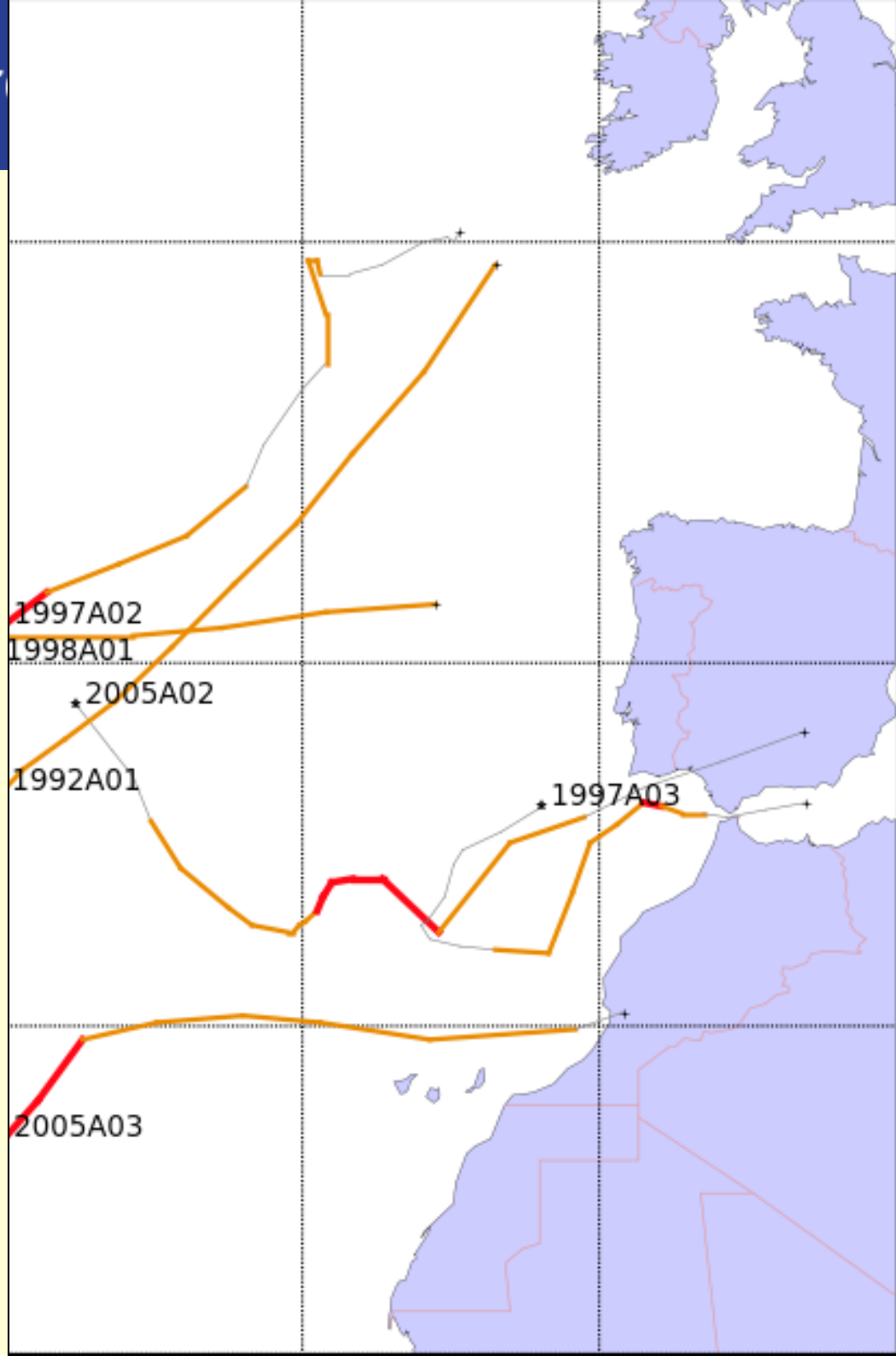


Results
Atlantic Ocean

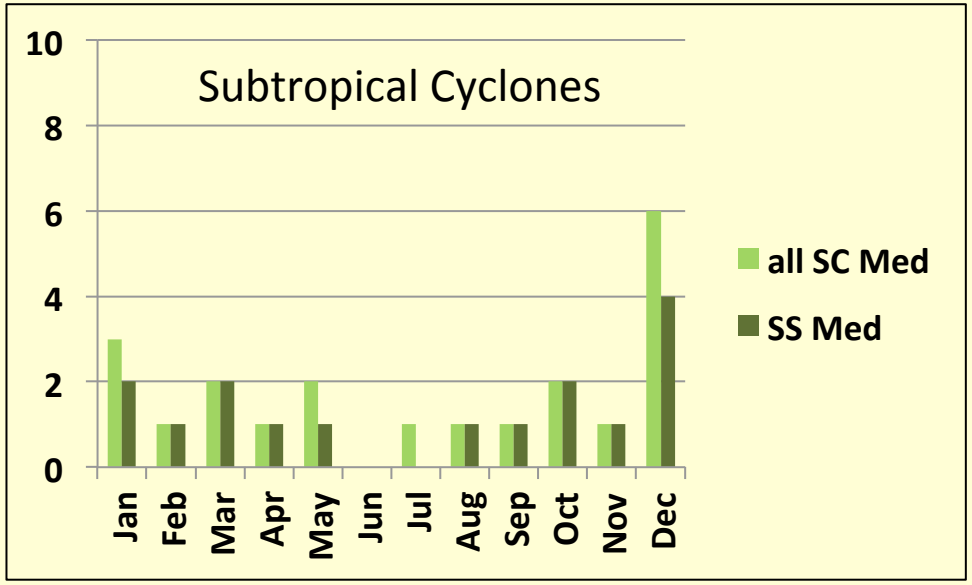
All Hurricanes 1982 – 2006

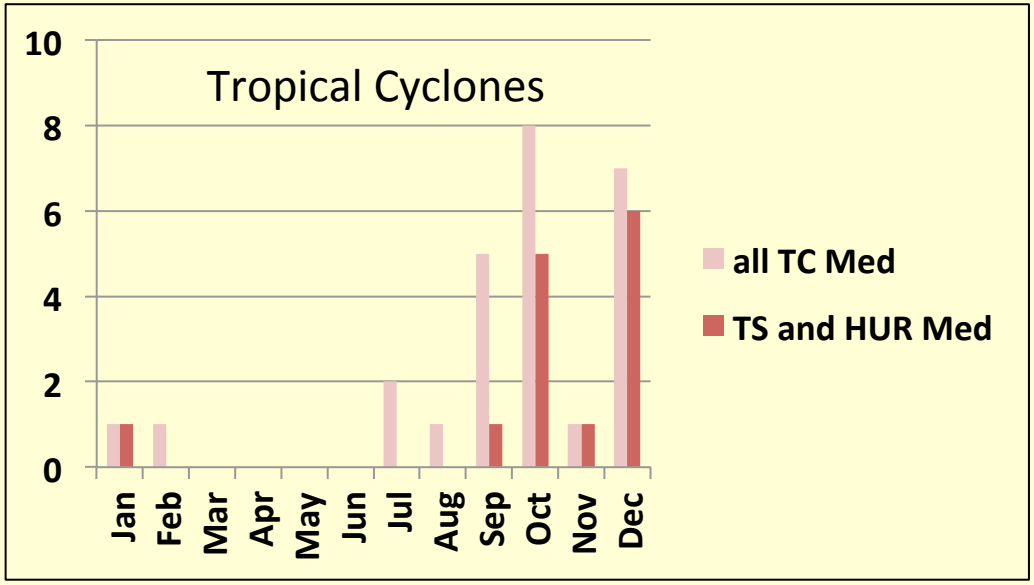
Depressions
Storms
Hurricanes

* Formation
\+ Dissipation



Results – Seasonal Statistics Mediterranean Sea





Number of cyclones per month (1982 – 2006)

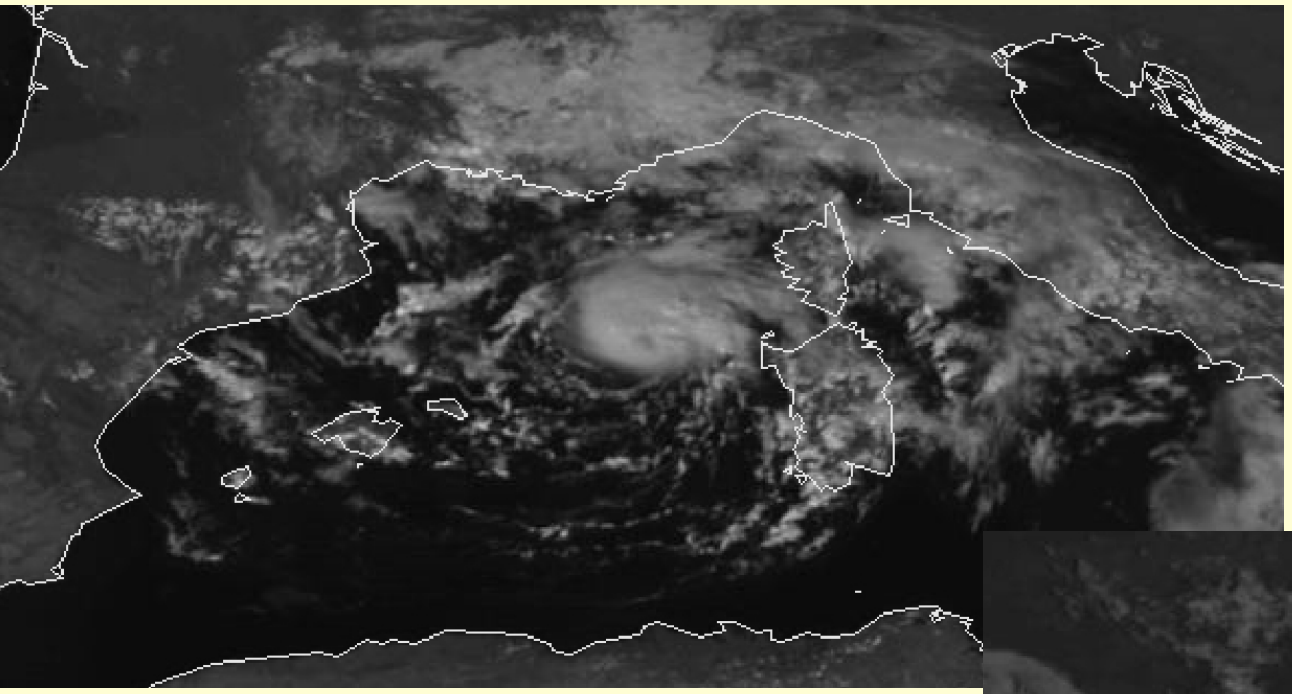
Subtropical storms occur around the year, maximum in early winter, minimum in early summer.

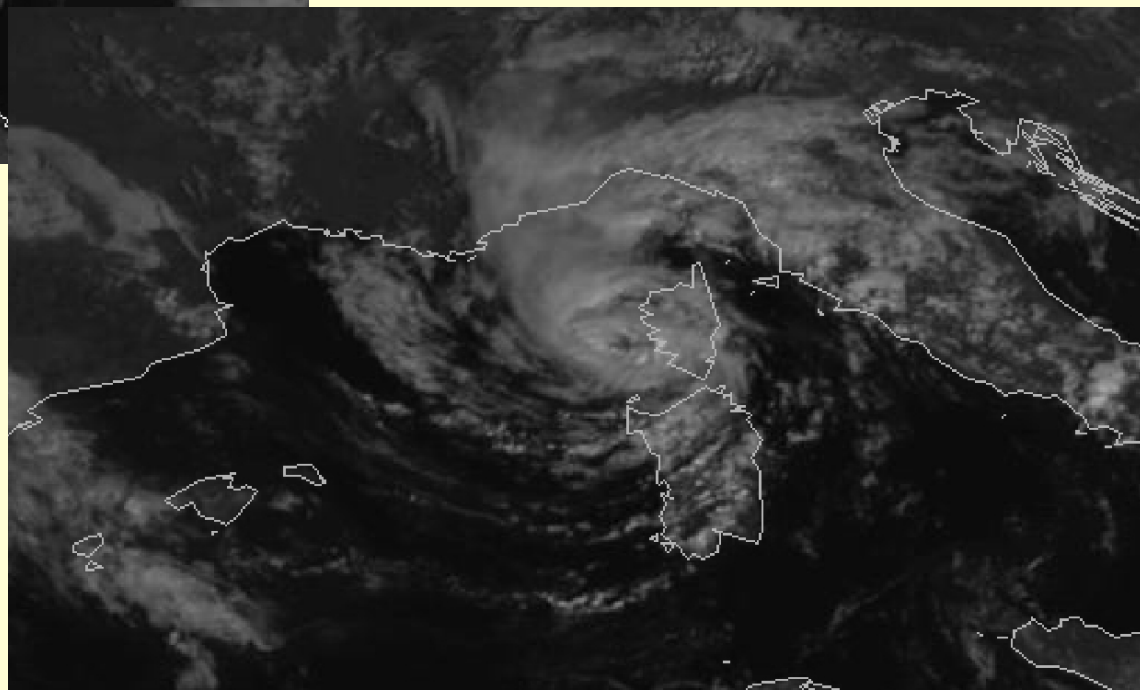
Tropical storms occur mainly in autumn and early winter:
Season from September to January

Results – Most Intense Cyclones

	Date and Time	Max Intensity T-No.	Min Pressure hPa	Max Sustained Winds kt	Category	Remarks
Black Sea						
2002B01	10.08.2002 06:00	3,0	1000	45	TS	
2005B01	28.09.2005 03:00	3,0	1000	45	SS	
Mediterra-nean Sea						
1983M02	30.09.1983 06:00	5,0	970	90	HUR	
1996M01	10.10.1996 00:00	5,0	970	90	HUR	Maximum intensity at landfall in Sicily
1996M02	10.12.1996 18:00	4,5	979	77	HUR	
1995M01	16.01.1995 06:00	4,5	979	77	HUR	
1982M01	03.12.1982 12:00	3,5	994	55	TS	Possible HUR 4,0 before landfall in Corse

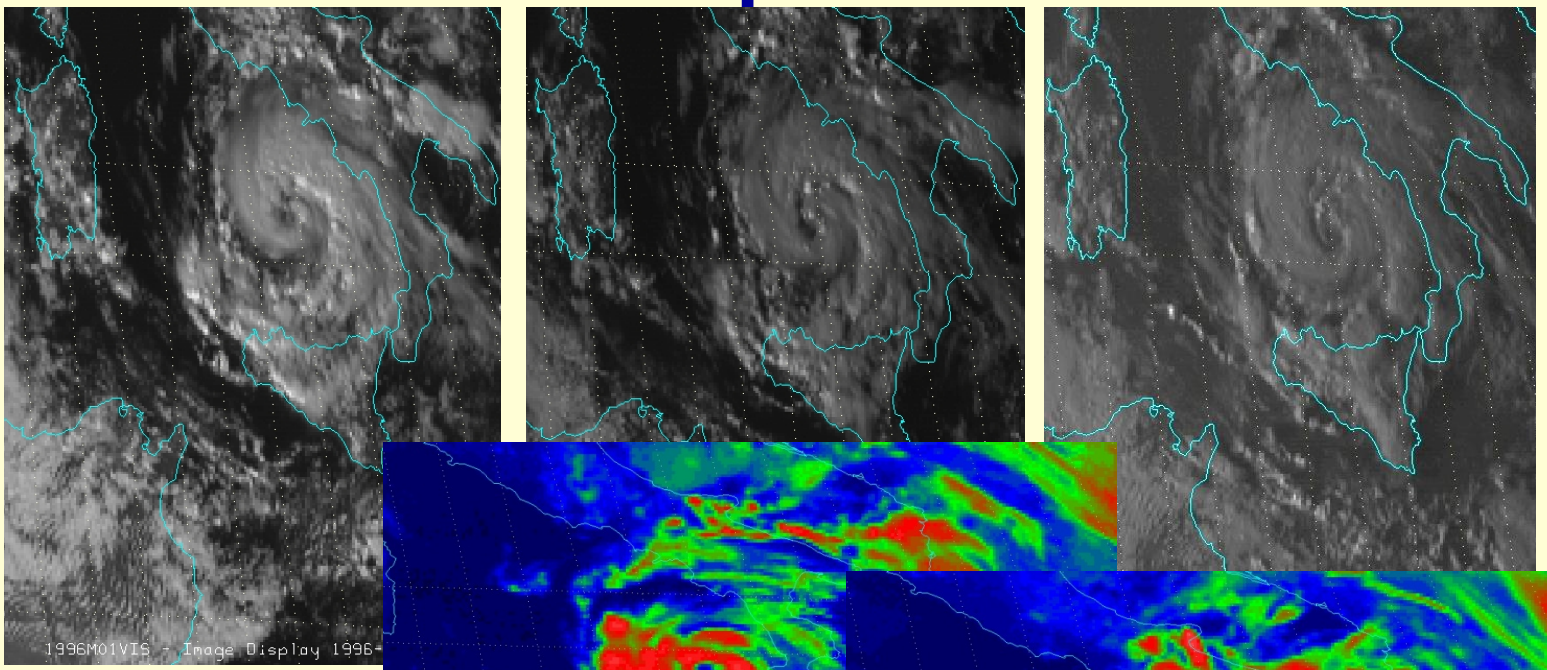
A few cases in pictures

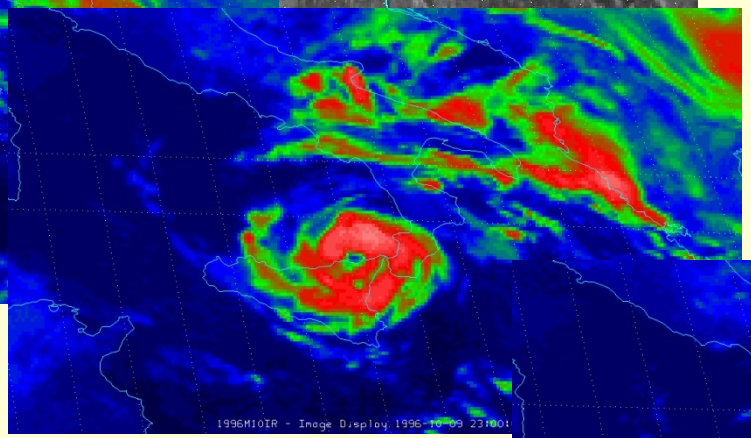


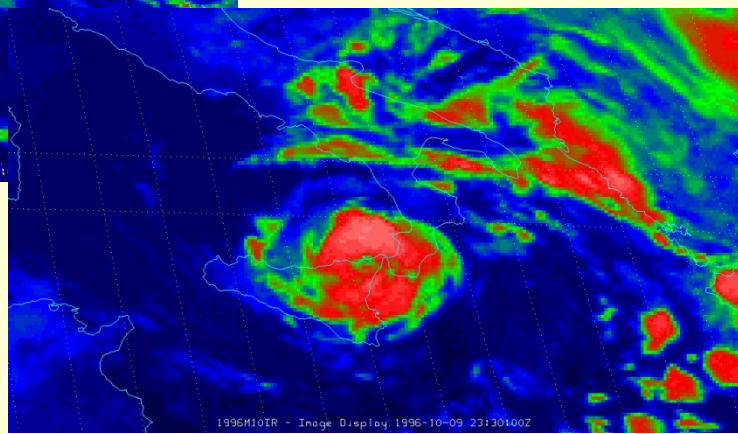


1983M02 – Sept. 1983, HUR max. 5,0

A few cases in pictures

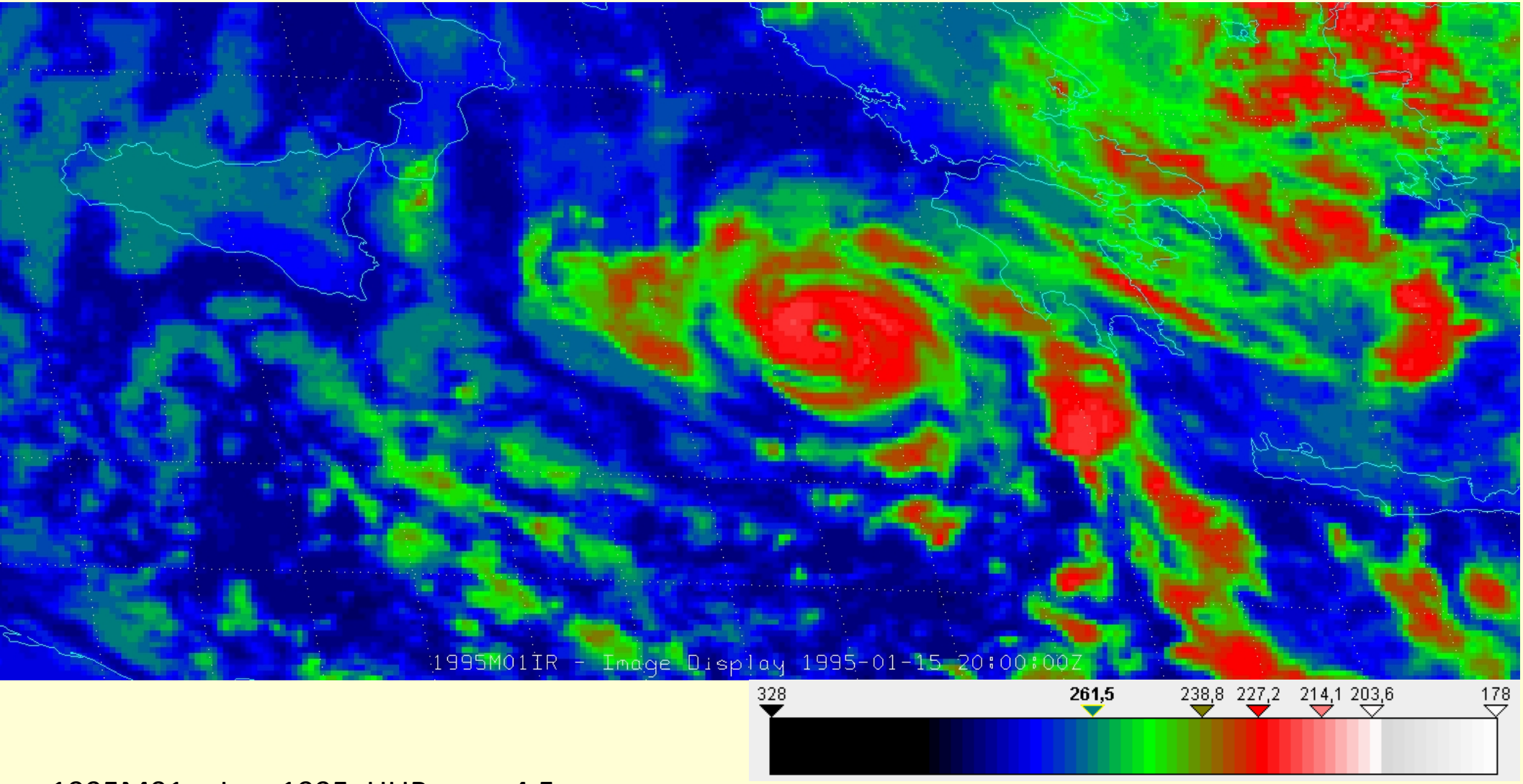






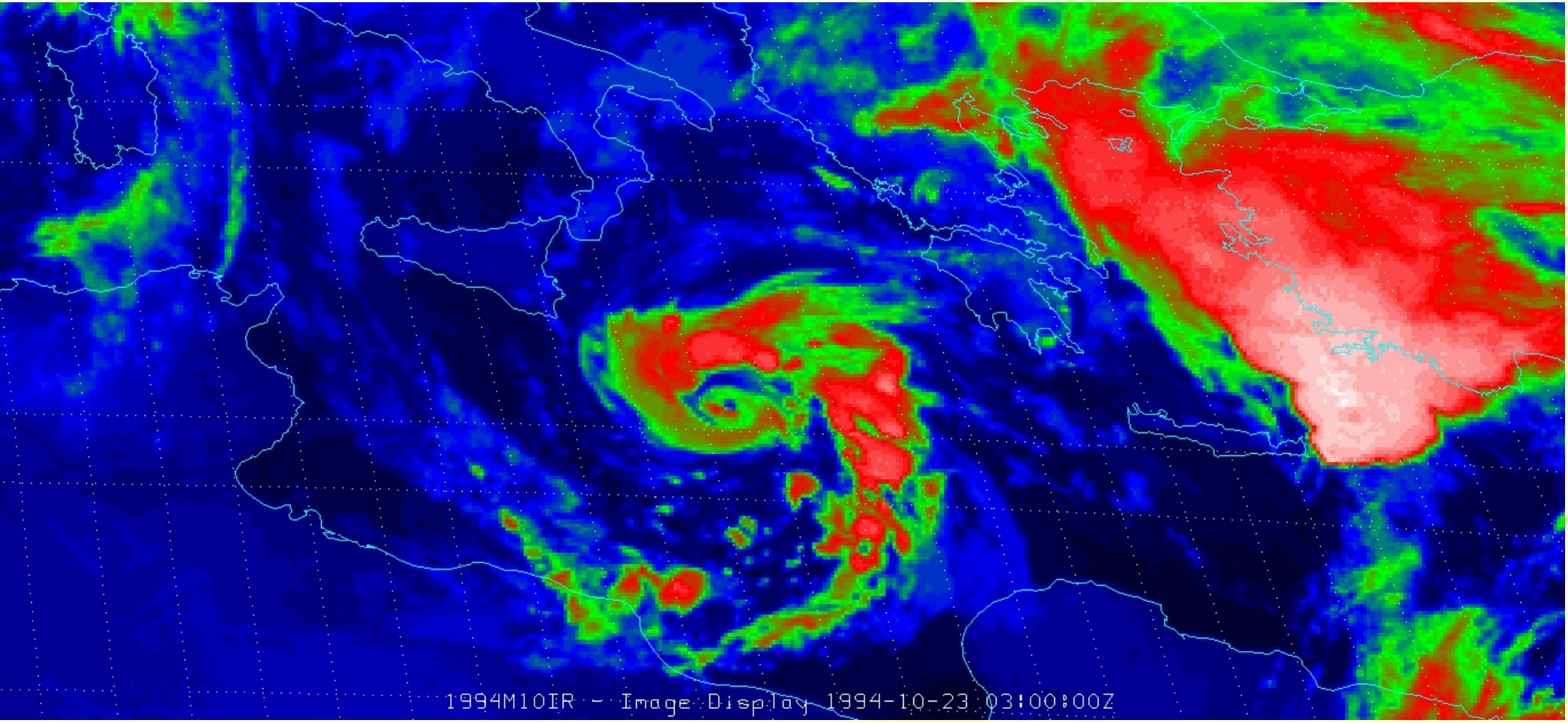
1996M01 – Oct. 1996, HUR max. 5,0

A few cases in pictures



1995M01 – Jan. 1995, HUR max. 4,5

A few cases in pictures



1994M03 – Oct. 1994, TS

Conclusions

- Dvorak method (for tropical cyclones) and Hebert and Poteat method (for subtropical cyclones) could be applied to the chosen study areas.
- A consistent climatology was set up (consistent in time and with other ocean basins worldwide).
- The Black Sea „produces“ very few cyclones in late summer.
- The Mediterranean Sea can spawn subtropical storms nearly year-round and tropical cyclones in autumn and early winter.
- The study area of the Atlantic Ocean spawns both subtropical and tropical cyclones mainly in autumn.

Outlook

A few suggestions for further work:

- Extend climatology with same methods into the MSG era.
- Prepare yearly overview of subtropical and tropical cyclone acitivity for the waters surrounding Europe.
- Compare results with ground observations and increasingly available satellite wind data from polar-orbiting satellites.
- Compare results with damage reports from the European Severe Weather Database (ESWD).

Thank you !

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www.essl.org

Source of all satellite imagery in this presentation:

Discussion - Hypothesizing

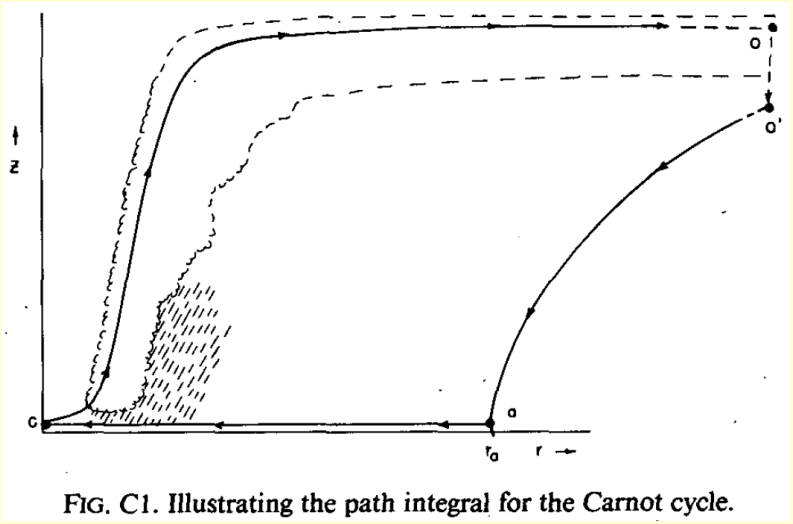


FIG. C1. Illustrating the path integral for the Carnot cycle.

(Emanuel, 1988)

It seems that the existence of "optimum atmospheric conditions" (see ingredients) for TC formation in most cases is much more important than a single SST threshold:

- Instability?
- Insignificant vertical shear?
- Moisture?
- LLCC (cyclonic low level convergence) as source of lift for CI and guarantee that deep convection stays together in a limited area and the Carnot cycles of different cells can work together to combine the effects positively and deepen a pre-existing low.

The combination of instability, low vertical shear and the existence of a LLCC are quite infrequent in the mid-latitudes.

In the Mediterranean shear and moisture seem to be the most limiting ingredients. Moisture often is reduced by drying out lee effects of the many surrounding mountain chains and by advection of dry Saharan desert air - with the result of many shrinking TCs in the southern Med.

Basic Definitions

Tropical Cyclone Formation Stages (Zehr, 1992)

Stage 0 (Pre-Genesis) is initially assigned to any cloud mass containing convection that a) persist for at least 24 h or b) fails to diminish from morning to evening according to the typical diurnal pattern.

Stage I (Suspect Area) is assigned to systems with current or recent (12-24 h) evidence of a LLCC, but with diminishing or steady convection not closely associated with the LLCC. The distinguishing mark of an LLCC is low-level concentration. The LLCC may go undetected in conventional data and infrared imagery but is often first evident in visible satellite imagery, especially loops at full resolution. If convection persists, the existence of an LLCC may also become apparent through the development of curved bands.

Basic Definitions

Tropical Cyclone Formation Stages (continued)

Stage II (Incipient Tropical Cyclone) is assigned to systems with current or recent evidence of an LLCC that has increasing convection relative to the diurnal cycle in its vicinity.

Commencement of this stage is often associated with organization of convection into curved bands.

Stage II systems should be monitored using the intensity guidelines (apply Dvorak classification).

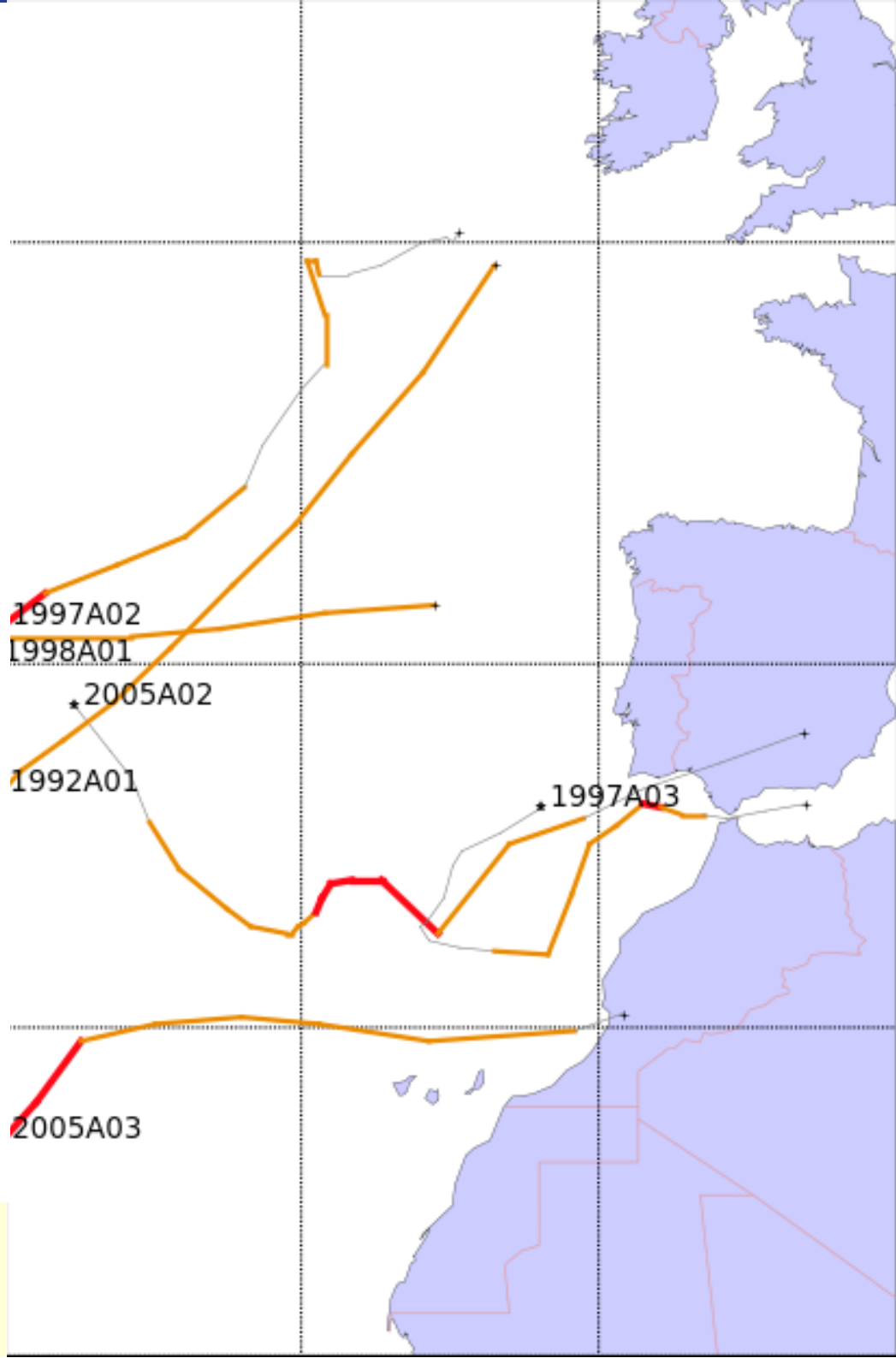
The critical events of development are establishment of a small-scale low-level vortex and collocated persistent convection.

Basic Definitions

Polar Low (PL)

A non-frontal low pressure system that has dominant characteristics of tropical cyclones, but appears over cold waters or subtropical waters with reduced SST during the cold season. According to an extrapolation of Emanuel (1988, assuming an ambient pressure of 1013 hPa and a relative humidity of 80 %) for outflow temperatures of warmer than -60 °C and SST of colder than 16 °C the maximum potential intensity of tropical-like cyclones is lower than 65 kt (derived from minimum pressure, assuming an empirical relationship between pressure and maximum sustained winds for the Atlantic, according to Dvorak, 1984).
Provided the given environmental conditions, a limit for intensification to severe tropical cyclone strength seem to be reached. Sustained wind speeds significantly higher than the hurricane threshold have not been observed so far in such an environment.

In addition to the definition of Rasmussen and Turner (2003): *"A polar low is a small, but fairly intense maritime cyclone that forms poleward of the main baroclinic zone (the polar front or other major baroclinic zone). The horizontal scale of the polar low is approximately between 200 and 1000 kilometres and surface winds near or above gale force."* we define as polar lows only those mesoscale vortices that are dominantly driven by convection (and not by baroclinic processes) and therefore possess a warm core. The term polar low is used for SST below 16 °C, while the terms subtropical or tropical cyclone (or hurricane) are used for appropriate systems over SST of 16 °C and warmer.



Similar track to Vince:

Hurricane of October 1842
(Vaquero et al., 2007)

Results – Most Intense Cyclones

Atlantic Ocean (study area)	Date and Time	Max Intensity	Min Pressure	Max Sustained Winds	Category	Remarks
2005A02	09.10.2005 18:00	4,5	979	77	HUR	NHC HUR Vince, landfall as a TD on Iberian Peninsula on 11.10.2005
1997A02	15.09.1997 18:00	4,5	979	77	HUR	NHC TS Erika drifting in from W
1997A03	06.10.1997 09:00	4,0	987	65	HUR	Maximum 4,5 possible with rapid development
2005A03	27.11.2005 18:00	4,0	987	65	HUR	NHC HUR Delta drifting in from WSW, rapidly becoming subtropical and extratropical over the Canary Islands
1998A01	26.09.1998 18:00	4,0	987	65	HUR	NHC HUR Ivan drifting in from W, weakening and becoming extratropical
1997A04	27.10.1997 06:00	3,5	995	55	TS	Near HUR strength at landfall time in N Portugal

Results – Starting Point for Automatic Detection and Intensity Rating Algorithms

Min IR temp (K)													Mean	StdDev
SS Atl	221	214	208	212	204								211,8	5,7
TS Atl	207	200	220										209,0	8,3
HUR Atl	215	215											215,0	0,0
SS Med and Black	217	226	215	210	208	217	220	221	218	211			216,3	5,2
TS Med and Black	215	209	209	210	224	215							213,7	5,3
HUR Med and Black	216	214	216										215,3	0,9
SS Max diametre deg lat dark grey	3,0													
SS Max diametre deg lat med grey														
TS and HUR Max diametre dark	2,0	2,0	2,4	2,5	3,3	4,0	2,5	3,1	6,3	9,0		2,5	3,6	2,1
TS HUR Max diametre medium	1,5	1,0	2,2	2,0	3,1 HUR	3,7 HUR	2,3 HUR	2,0	6,1	9,0	1,2	2,0	3,0	2,2

No usable primitive key parameter. Data unavailable for many historic cases.

Minimum IR temperatures of cyclones show no correlation with strength and allow no distinction between subtropical and tropical nature.

Diametre of central features is not correlated with strength (consistent with literature).

Results – Starting Point for Automatic Detection and Intensity Rating Algorithms

- Easy approach not practicable below hurricane stage.

- Statistics for minimum IR temperatures and for central feature diametres (for certain temperature thresholds) do not show usable correlations.

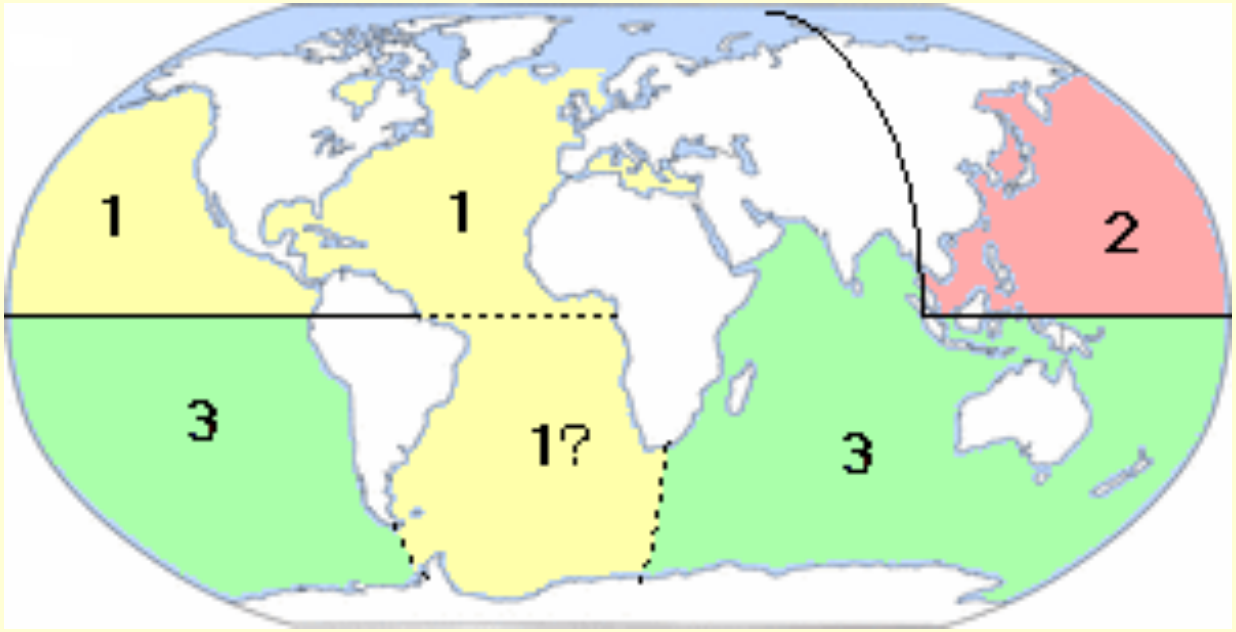
- At NOAA Satellite Service Division (NESDIS SSD) the manual Dvorak technique continues to be the standard method for daily intensity estimates of tropical cyclones. While first generation algorithms were strongly dependent on a manual cloud system center input, the new Advanced Dvorak Technique (ADT) utilizes an objective storm center determination scheme and cloud pattern determination logic. It also can be applied to all phases of the TC lifecycle; something that previous automatic schemes could not do. It would be interesting to test ADT for systems in the area of this study.

Basic Definitions

Maximum sustained wind (1min or 10 min average):

0		*34 kt*	*64 kt*
Disturbance	Depression	Storm	Hurricane

Regional names for the same type of storm (mature stage):



Map source: Wikipedia

1 … Hurricane

2 … Taiphoon

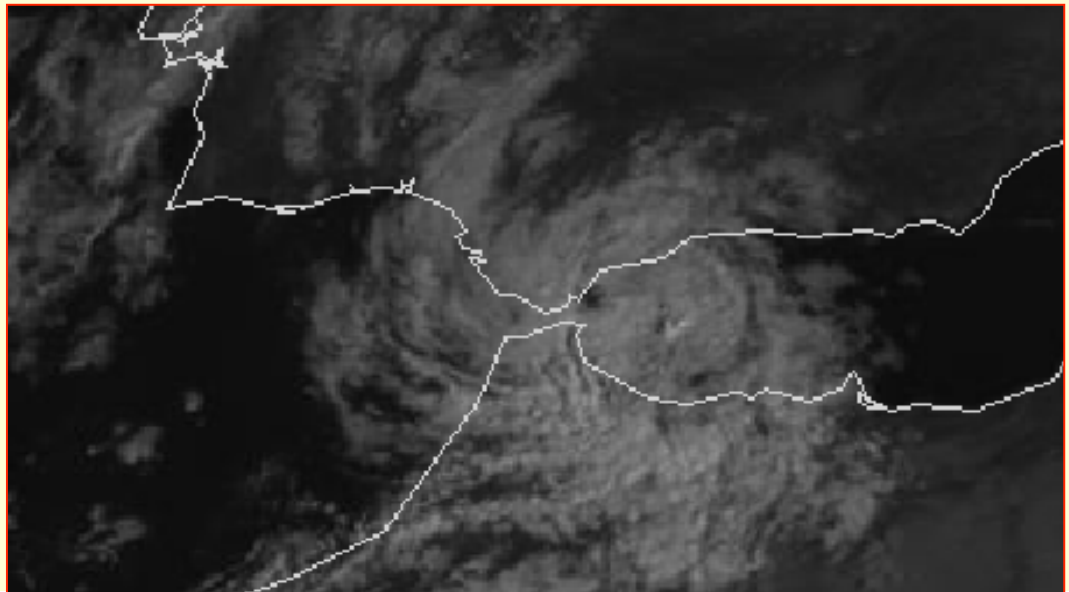
3 … Cyclone and other regional names

Basic Definitions - Names

What is the most neutral term to be used in a region (like the Black Sea and the Mediterranean Sea), where no generic term exists (because of infrequent TCs)? Hurricane? Tropical Cyclone? Or simply Cyclone?

The term “hurricane” has a few advantages compared to “tropical cyclone”, e.g.:

- “Tropical” misplaced in a mediterranean winter environment.
- Well understood by the public and well-connected with its damage potential.
- Term used on the western side of the Iberian Peninsula, so why not on the eastern?
- No confusion with general term “tropical cyclone” for all tropical system intensities from tropical depressions (MSWs < 34 kt) to hurricane-strength (MSWs >64 kt).

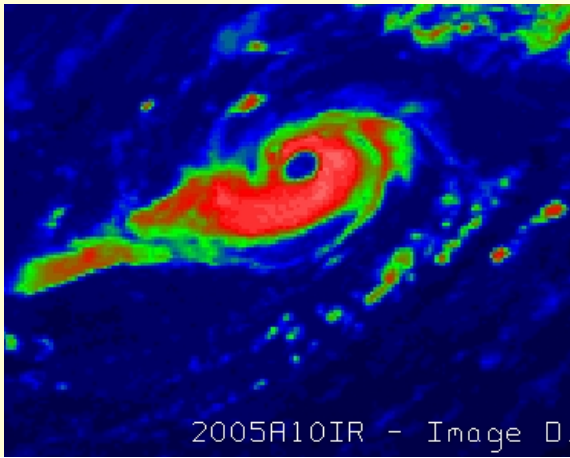


Basic Definitions

Tropical Cyclone

A **warm-core non-frontal synoptic- or meso-scale cyclone**, originating over tropical or subtropical waters, with **organized deep convection** and a **closed surface wind circulation about a well-defined center**. Once formed, a tropical cyclone is maintained by the extraction of heat energy from the ocean at high temperature and heat export at the low temperatures of the upper troposphere. In this they differ from extratropical cyclones, which derive their energy from horizontal temperature contrasts in the atmosphere (baroclinic effects).

Definition sources: NOAA NHC and GGTCF



Hurricane Vince near Madeira, Oct. 2005

Basic Definitions

Tropical Disturbance (TDi)

A discrete tropical weather system of apparently organized convection -- generally 100 to 300 nmi in diameter - originating in the tropics or subtropics, having a nonfrontal migratory character, and maintaining its identity for 24 hours or more. It may or may not be associated with a detectable perturbation of the wind field.

Tropical Depression (TD)

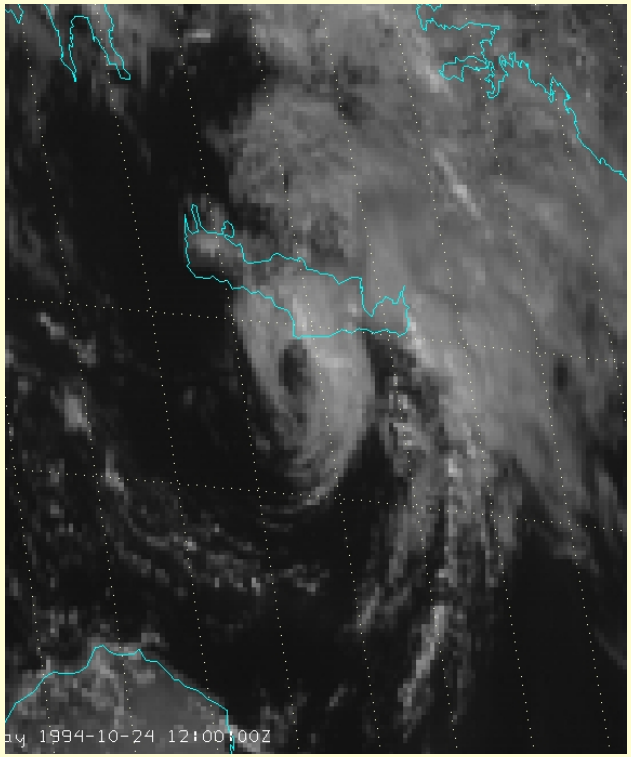
A tropical cyclone in which the maximum sustained surface wind speed (using the U.S. 1-minute average) is 33 kt or less.

Tropical Storm (TS)

A tropical cyclone in which the maximum sustained surface wind speed (using the U.S. 1-minute average) ranges from 34 kt to 63 kt.

Intense (or severe) Tropical Cyclone , Hurricane (TC , HUR)

A tropical cyclone in which the maximum sustained surface wind (using the U.S. 1-minute average) is 64 kt or more.



TS 1994M03 on 24 Oct. 1994

Definition sources: NOAA NHC and GGTCF

Basic Definitions

Remnant Low (RL)

A post-tropical cyclone that no longer possesses the convective organization required of a tropical cyclone and has maximum sustained **winds of less than 34 knots**. The term is most commonly applied to the nearly deep-convection-free swirls of stratocumulus.

Extratropical (EX)

A term used in advisories and tropical summaries to indicate that a cyclone has lost its "tropical" characteristics.
The term implies both poleward displacement of the cyclone and the conversion of the cyclone's primary energy source from the release of latent heat of condensation to baroclinic (the temperature contrast between warm and cold air masses) processes. It is important to note that cyclones **can** become extratropical and **still retain winds of hurricane or tropical storm force**.

Definition sources: NOAA NHC and GGTCF

Basic Definitions

Subtropical Cyclone (SC)

A non-frontal low pressure system that has characteristics of both tropical and extratropical cyclones. This system is typically associated with an upper-level cold low with circulation extending to the surface layer and maximum sustained winds generally occurring at a radius of about 100 miles or more from the center. In comparison to tropical cyclones, such systems have a relatively broad zone of maximum winds that is located farther from the center, and typically have a less symmetric wind field and distribution of convection. Umbrella term for:

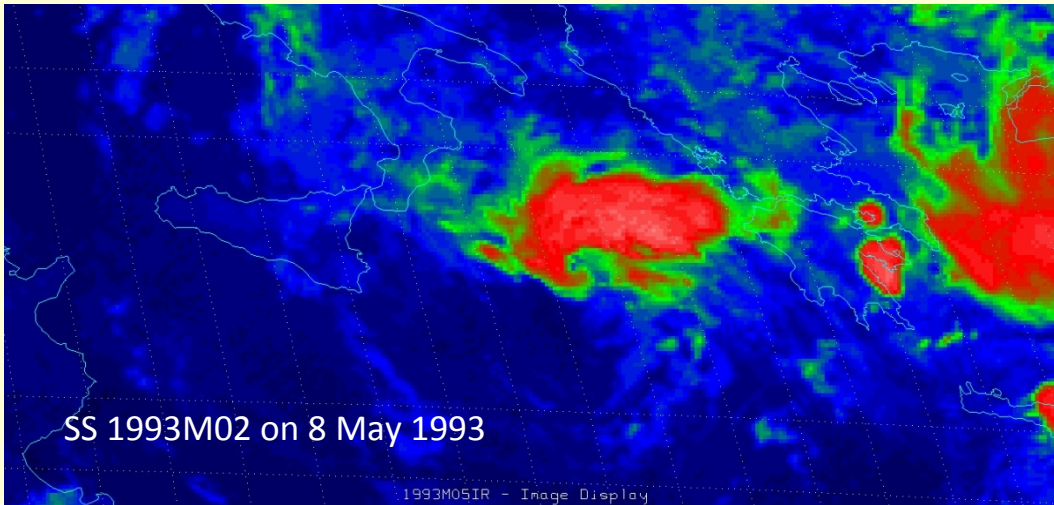
Subtropical Depression (SD)

A subtropical cyclone in which the maximum sustained surface wind speed (using the U.S. 1-minute average) is 33 kt or less.

Subtropical Storm (SS)

A subtropical cyclone in which the maximum sustained surface wind speed (using the U.S. 1-minute average) is 34 kt or more.

Definition sources: NOAA NHC and GGTCF



SS 1993M02 on 8 May 1993

Ingredients for Tropical Cyclones

Ingredients for deep convection …

… Instability

… Moisture, most preferential over water as low-friction surface

… Lift, most preferential by low level cyclonic convergence (a low level circulation centre LLCC)

Absence of significant vertical wind shear (shear between 850 hPa and cloudtop-region < 10 m/

Warm Core Low

Compare for organized convection in MCSs:

Ingredients for deep convection …

… Instability

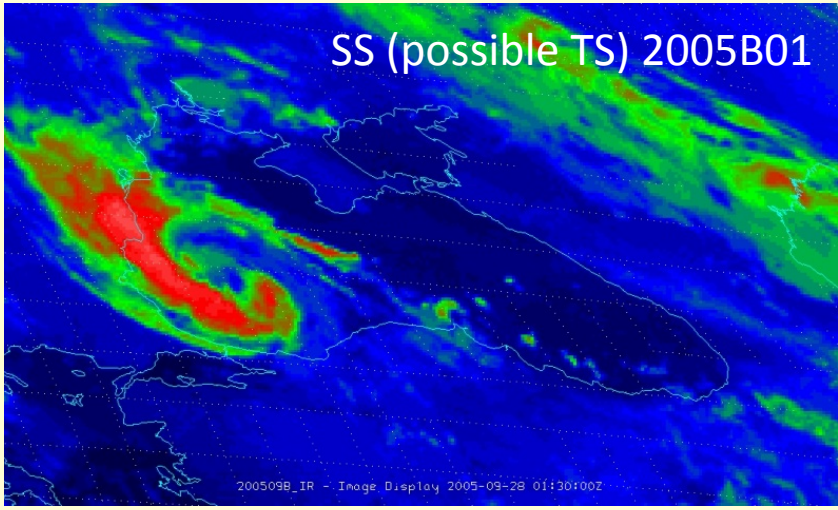
… Moisture

… Lift, most preferentially by linear convergence

Significant wind shear

Cold-pool and meso-high with leading squall-line

Basic Definitions - Names



Discussion will go on about the best name.

Most important:

“Hurricane”, “((Severe) Tropical) Cyclone” and “Taiphoon” are synonyms for a single type of storm.

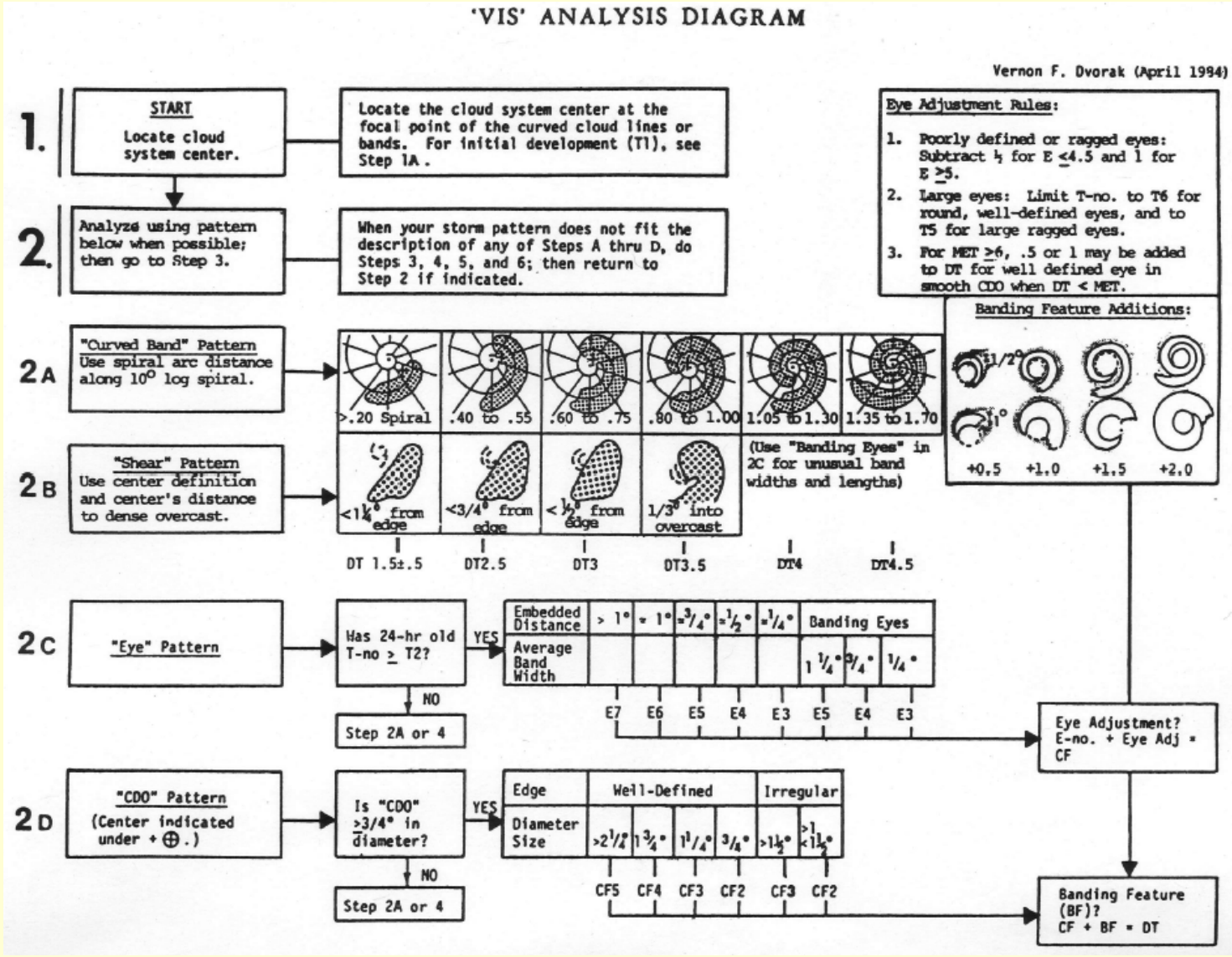
As long as this is clear, the name is not too important. We use “Hurricane” for the Atlantic (as it is the official WMO term for this basin) and both, “Hurricane” and “Tropical Cyclone” as synonyms for the Mediterranean and Black Sea.

Please, no Blackicane!

Research Method

STEP 2

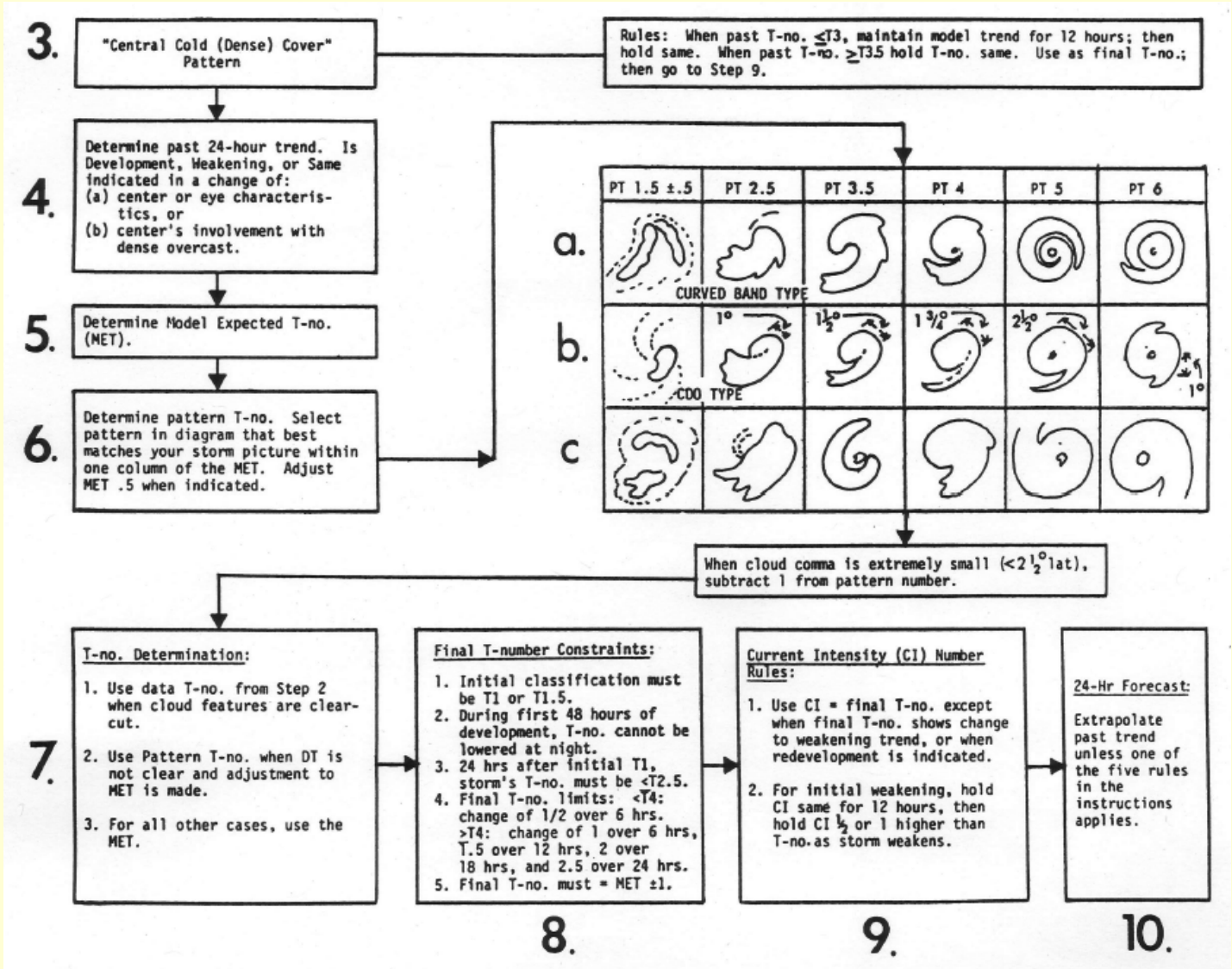
- Dvorak decision tree for VIS, part 1



Research Method

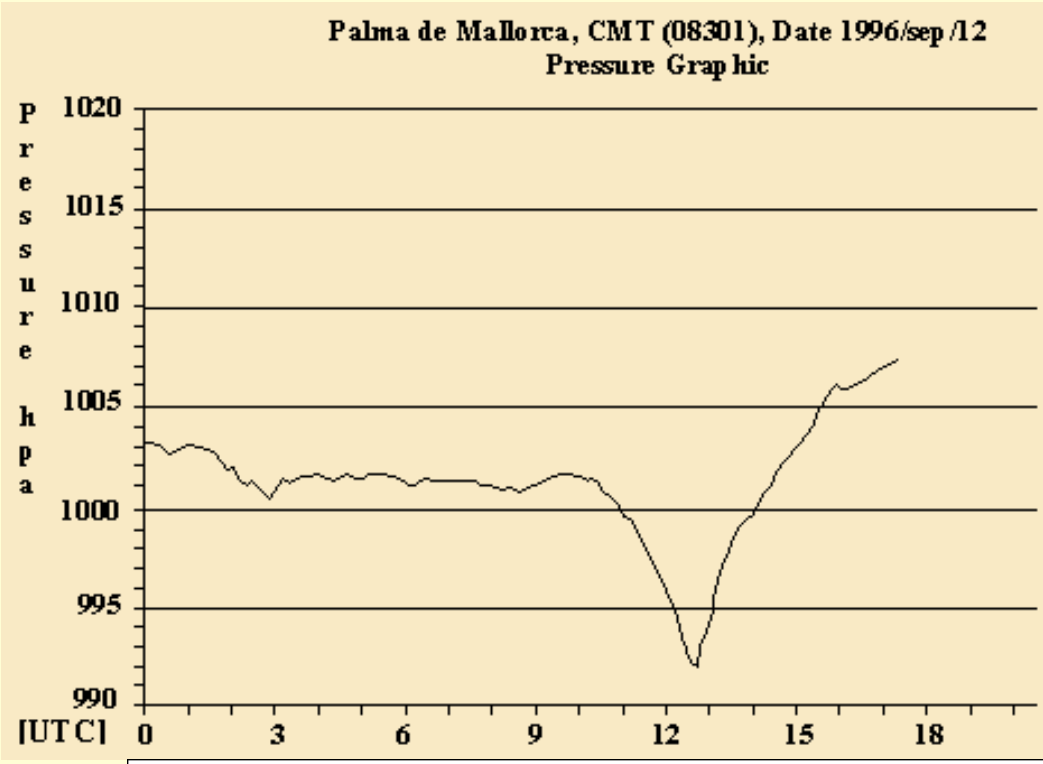
STEP 2

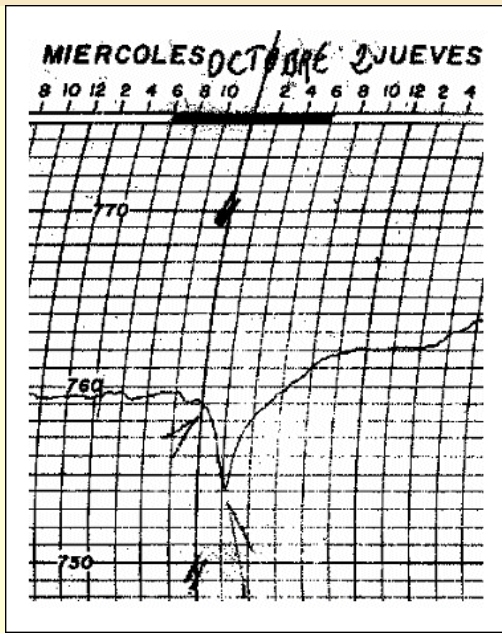
- Dvorak decision tree for VIS, part 2

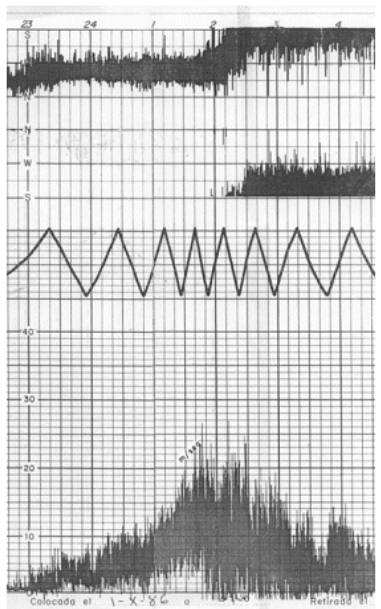


Point of Departure

- Analyses and case studies now and then in literature (scientific and grey) and training courses (like EUMETCAL).
- Historical and recent satellite images of systems looking very much „tropical“ in some cases.
- Weather station reports of severe weather and damage reports in the European Severe Weather Database (ESWD) related to tropical-like cloud structures in satellite images.







EUMETCAL examples 09/1996, 10/1986

Point of Departure - continued

- NOAA Satellite Service Division (NESDIS SSD) recently (2011) provided tropical storm positions and bulletins based on EUMETSAT MSG data.
- Increasing discussions in community internet blogs and experimental forecasting projects (like ESTOFEX).
- Methods for worldwide consistant tropical storm (Dvorak) and subtropical storm (Hebert and Poteat) analyses are available.

```
TXMM21 KNES 080630
TCSMED

A.  01M (NONAME)

B.  08/0600Z

C.  41.5N

D.  5.8E

E.  THREE/MET-9

F.  T3.0/3.0/D1.5/24HRS

G.  IR/EIR/SWIR

H.  REMARKS...CONVECTION WRAPS ALMOST .7 ON LOG10 SPIRAL YIELDING A DT
OF 3.0.  MET = 2.5 AND PT = 3.0.  FT IS BASED ON DT.

I.  ADDL POSITIONS

    NIL


...KIBLER
```

Research Method

Hebert and Poteat (1975) provide rules and cloud signatures for intensity estimation of subtropical (ST) cyclones:

Basic Definitions - Sources

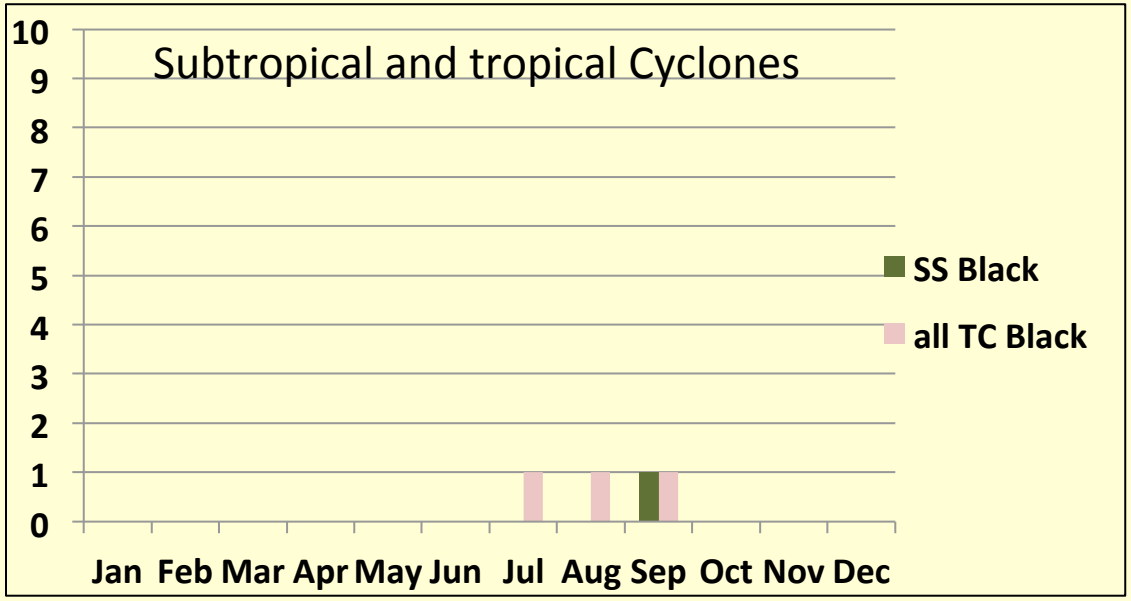
- **Global Guide to Tropical Cyclone Forecasting (GGTCF)** (a best practice document edited by Greg Holland et al. – BOM Australia, SAIC Miami, CIMSS Wisconsin, NOAA NWS, NHC Miami, NWS Japan, MeteoFrance, NWS India)

  Summarizes the current state of knowledge and provides the best overview of definitions.

- **NHC definitions** are best documented and are used primarily together with methods described in the **original literature of Dvorak, and Hebert and Poteat**.

- Additional definitions provided in the GGTCF including **Zehr-Stages** and analysis procedures.

Results – Seasonal Statistics
Black Sea

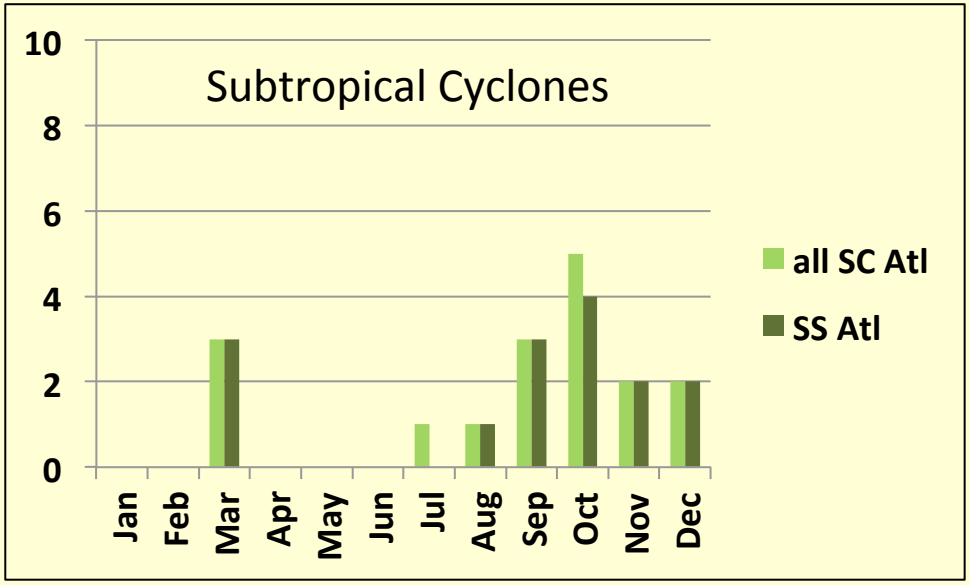


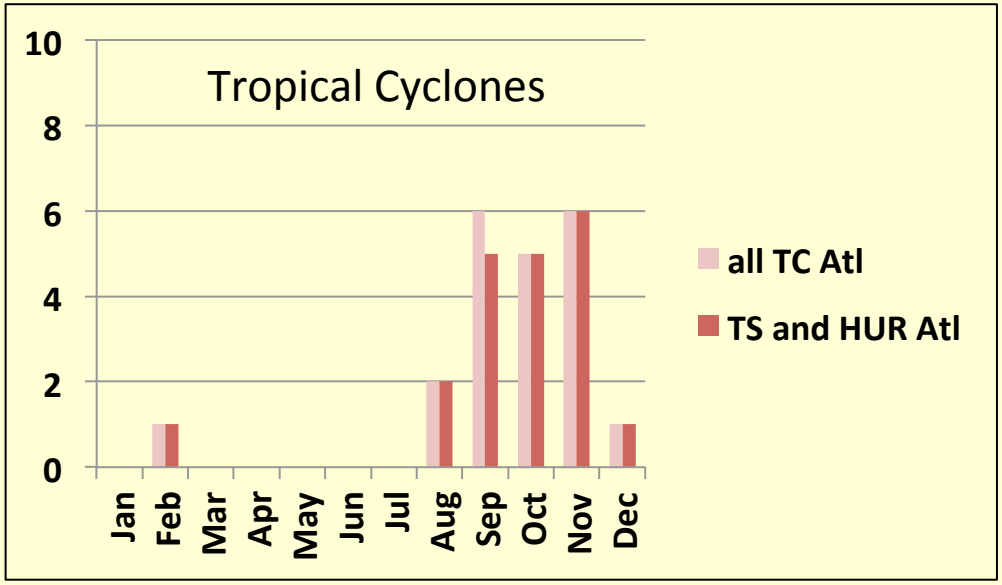
Number of cyclones per month (1982 – 2006)

Very few cases.

Based on these few cases:
Season from July to September

Results – Seasonal Statistics
Study area of Atlantic Ocean





Number of cyclones per month (1982 – 2006)

Subtropical storms occur mainly in autumn, second maximum in early spring.

Tropical storms occur mainly in autumn:
Season from August to February – with uncertainties based on limited number of cases!

A few more cases in pictures