MSG based instability indices

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Chief Scientist: Nowcasting and very short range forecasting
(Slides contributed by Marianne Koenig, EUMETSAT and Cassandra Pringle)

Severe Weather Forecasting Demonstration Projects (WMO CBS SWFDP)

- Fourth meeting of the CBS-SWFDP Steering Group in Geneva, February 2012:
  - **Challenge for the SWFDP: "the need for very short-range forecasting tools, to address especially the rapid onset of localized severe thunderstorms which can produce heavy precipitation and strong wind, given the absence of adequate real-time observational networks, especially weather radar coverage."**
  - The usefulness of EUMETSAT **satellite based instability products**, such as the Global Instability Index, for nowcasting purposes was recognized
  - Also agreed that **real time satellite rainfall estimates** have proven particularly useful in regions where rain gauges and radar coverage is sparse.

The MSG MPEF: Meteorological Products Extraction Facility

- MPEF is part of the Application Ground System and constitutes, together with the Satellite Application Facilities (SAF) the source of the Meteorological Products provided by the MSG system
- As a general principle, the MPEF will extract products on a synoptic scale (< 100 km)
- These MPEF products are available to all MSG receiving countries (free)

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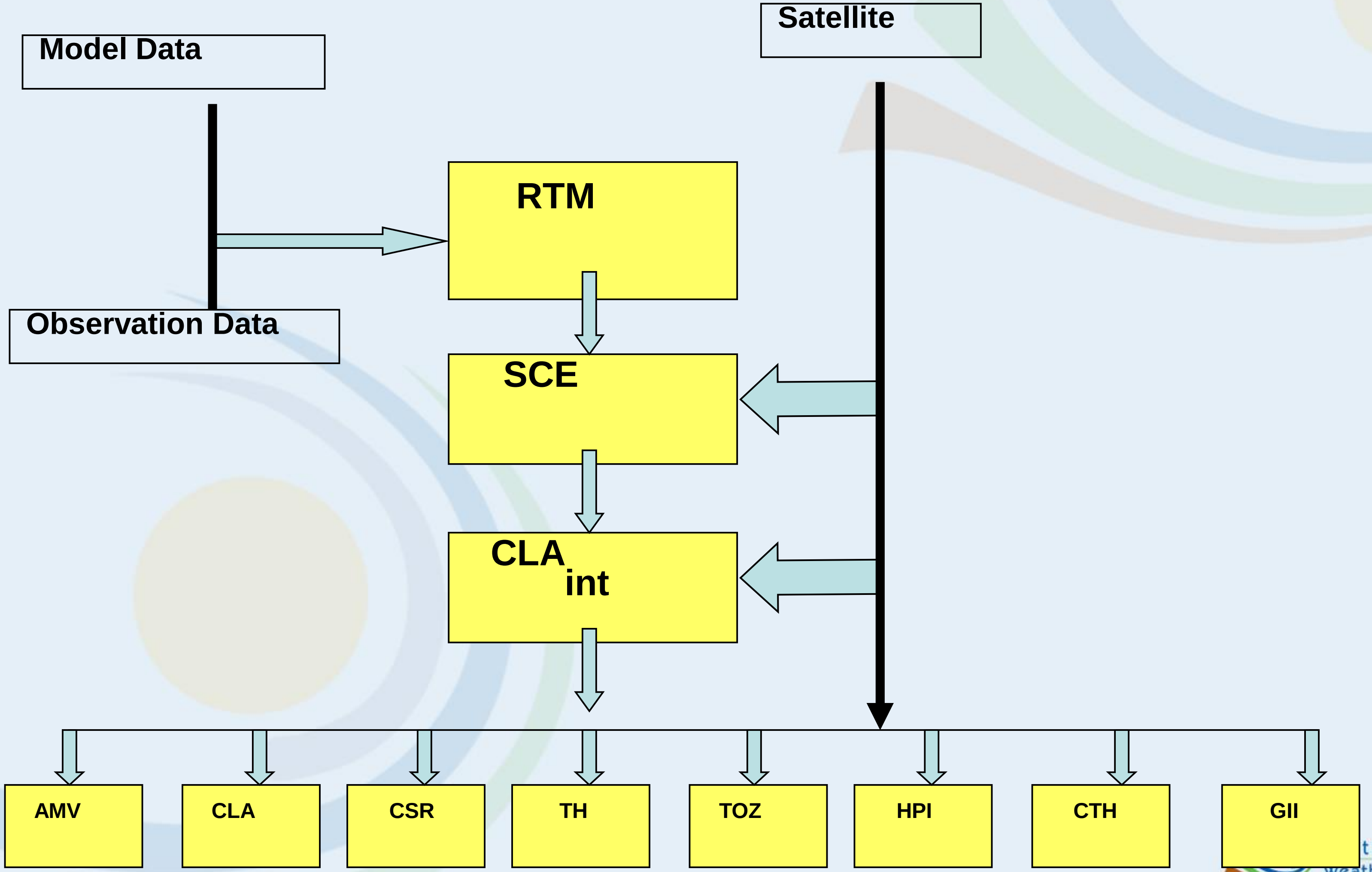
Algorithm Overview



MSG MPEF Products Baseline (GTS/EUMETCast/UMARF)

- Atmospheric Motion Vectors (AMV)
- Calibration Monitoring (CAL-MON)
- Clear Sky Radiance (CSR)
- Clear Sky Reflectance Map (CRM)
- Climate Data Set (CDS)
- Cloud Analysis (CLA)
- Cloud Top Height (CTH)
- Global Instability Index (GII)
- ISCCP Dataset (IDS)
- Precipitation Index (PI)
- Total Ozone (TOZ)
- Tropospheric Humidity (TH)

Some internal Products:

Sea Surface temperature (SST)

Scenes Analysis (SCE)

Radiative Transfer Model (RTM)

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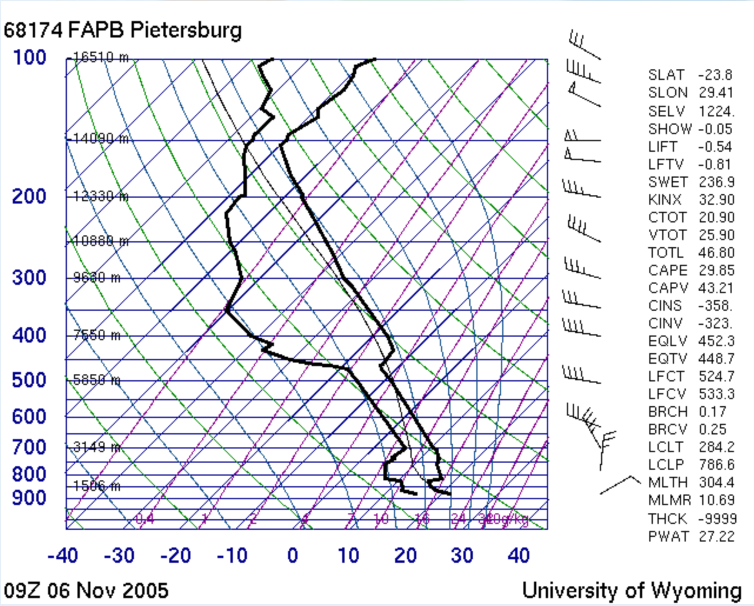
MSG MPEF Product: Global Instability Index GII

- Together with a forecasted temperature and humidity profile as initial information, the MSG infrared channels are used to infer updated profiles (only for cloud free conditions)
- Empirical instability parameters are inferred from these profiles (Lifted Index, K-Index)
- The Total Precipitable Water Content is a further airmass parameter, inferred from the humidity profile and part of the GII product

Why the need for satellite based instability indices?

- Parameters that would indicate whether or not the conditions are favourable for thunderstorm development.
- Describe how unstable the atmosphere is or indicate the likelihood of convection.
- Traditionally, these indices are taken from temperature and humidity soundings by *radiosondes*.
- Radiosondes are expensive!



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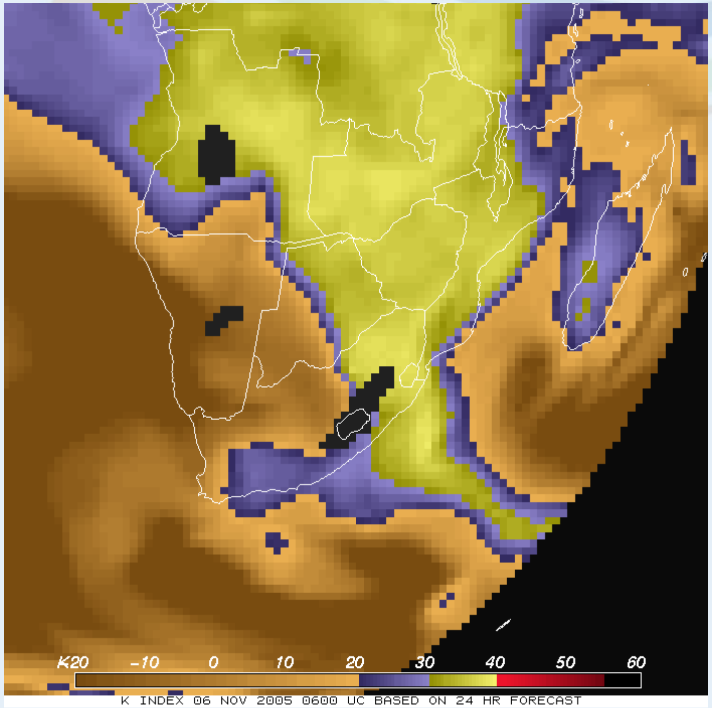
- Since *numerical weather prediction models* can forecast these factors of the atmosphere, they can forecast the instability also.
- A number of instability indices have been defined to describe such situations.



Atmospheric instability: The Global Instability Index (GII)

- As radiosondes are only of very limited temporal and spatial resolution there is a demand for satellite-derived indices which can provide the information every 15 minutes!
- The basis of the GII methodology is:
  - Together with the satellite *measured brightness temperatures* and some a priori information of the atmospheric profile (from the *Numerical Weather Prediction model*) a local profile is derived, and instability indices are computed from this local profile.

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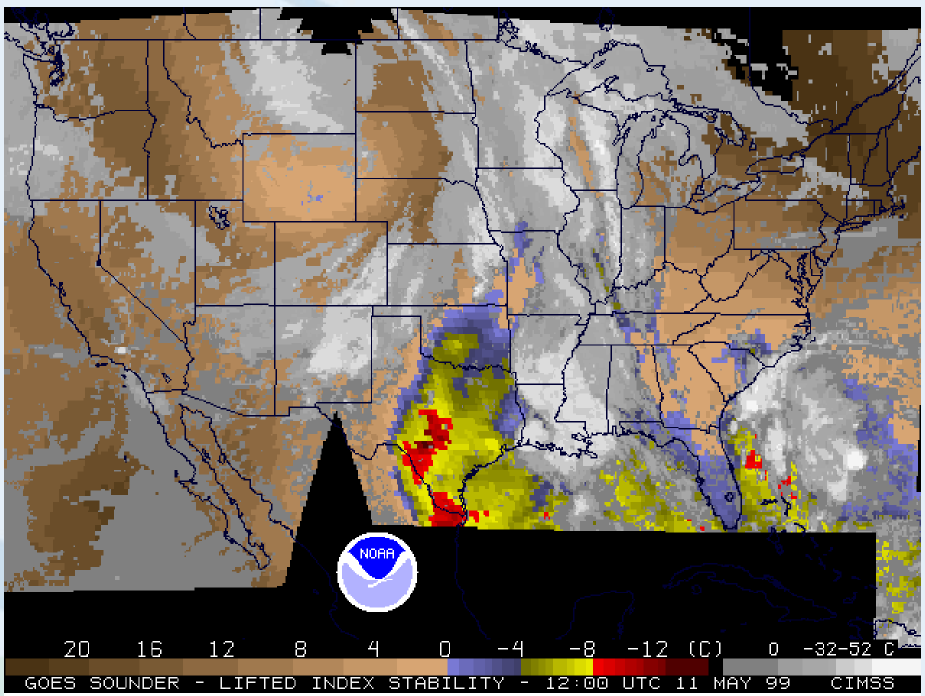
History – USA and GOES

- A global (Meteosat) coverage of instability information (GII = Global Instability Indices) satellite product was one of the drivers of the channel definition on MSG
- Heritage: Similar products from the GOES Sounder, provided by CIMSS (Univ. Wisconsin)

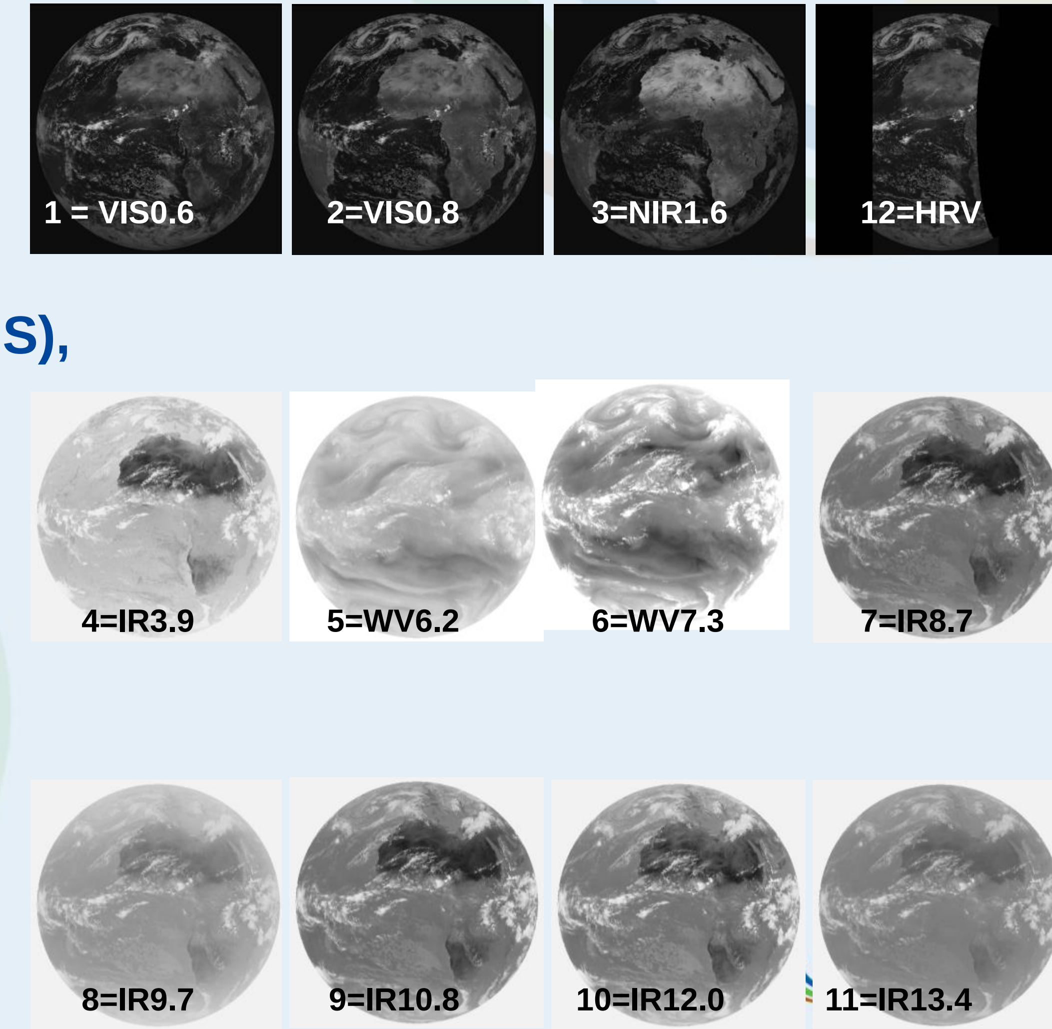


Shades of brow ⇒ stable air

Blue to yellow to red ⇒ increasing instability

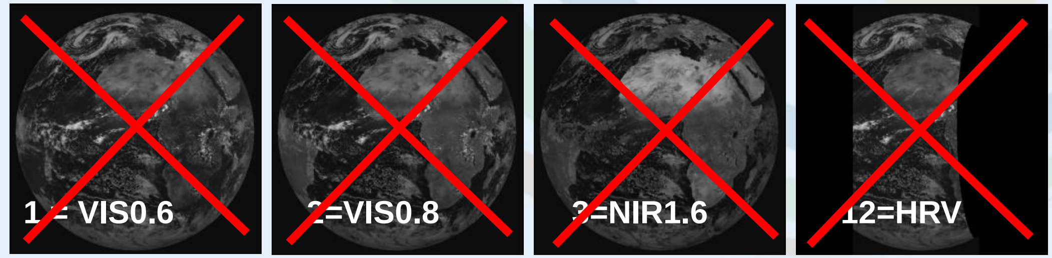
MSG Channels

12 available channels on MSG,
4 in the solar spectral range (VIS),
8 in the infrared (IR)

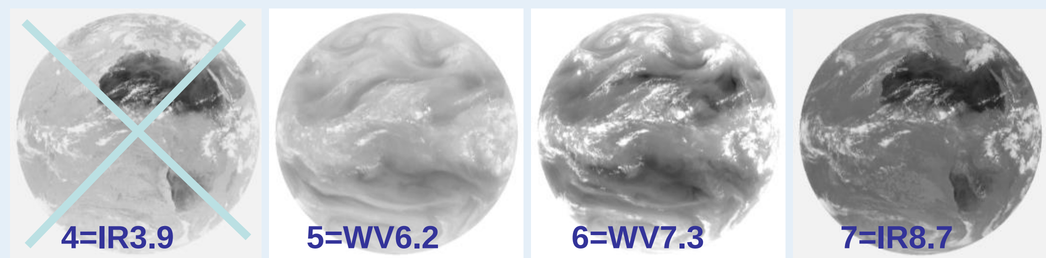


MSG channels we cannot use for a vertical profile of temperature and humidity

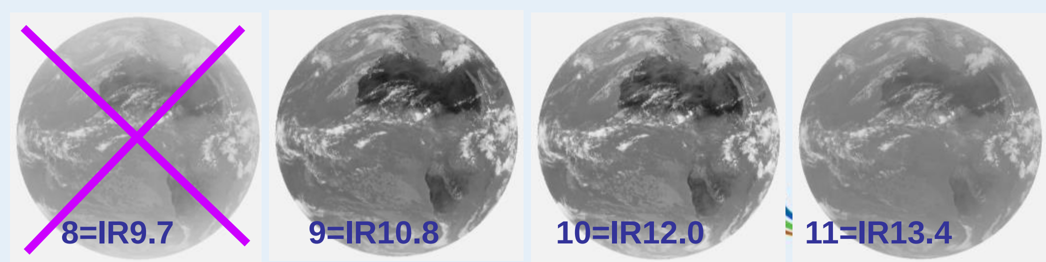
No temperature/humidity information in solar channels



Temperature information in IR3.9 mixed with solar contribution (during daytime)

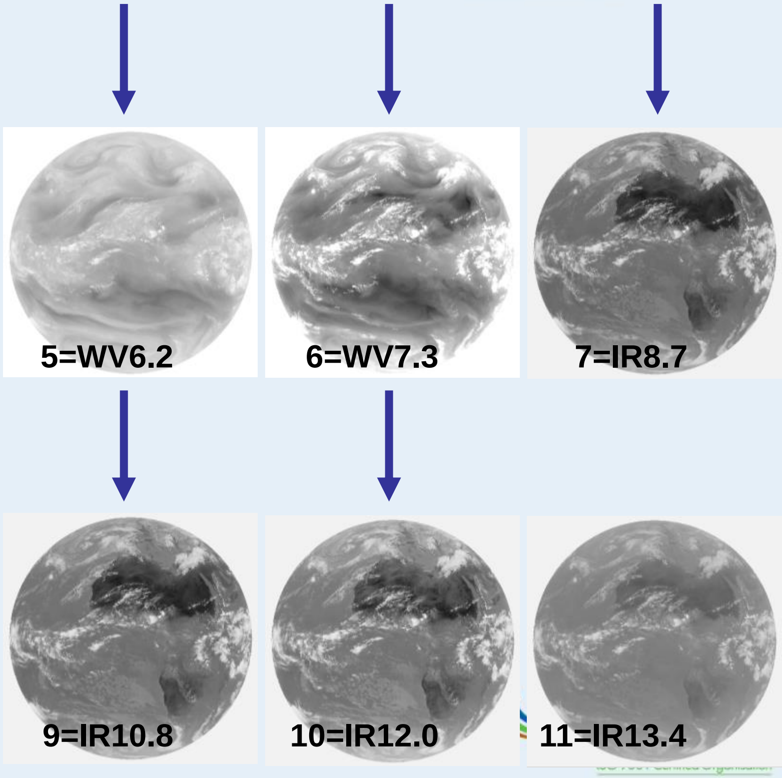


Too much ozone information in IR9.7



MSG channels useful for a vertical profile

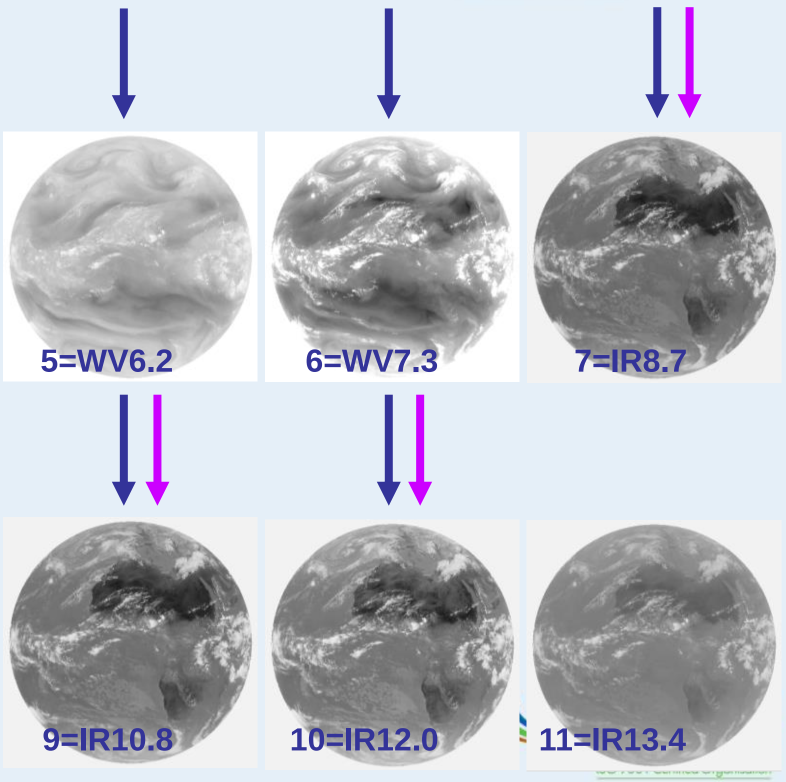
Humidity information in various levels



MSG channels useful for a vertical profile

Humidity information in various levels

Information on surface temperature

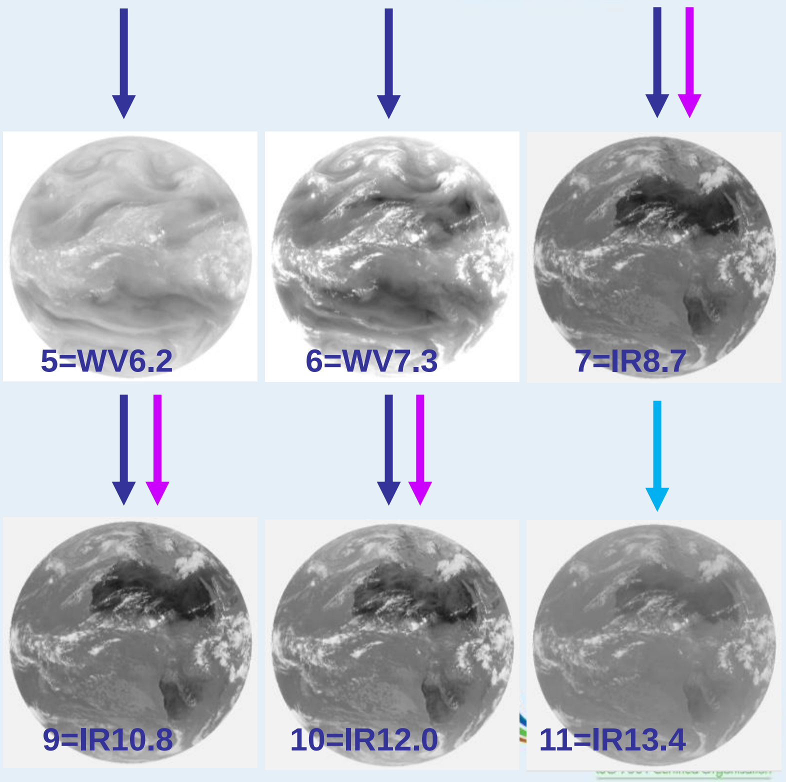


MSG channels useful for a vertical profile

Humidity information in various levels

Information on surface temperature

Information on mid-level air temperature



Retrieval Concept (1)

- From NWP: Forecast temperature and humidity profile: $T(p)$, $q(p)$

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↓ **Radiative transfer model**

Expected MSG brightness temperatures in 6 channels TB (MSG)

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- From NWP: Forecast temperature and humidity profile: T(p), q(p)

↓ **Radiative transfer model**

Expected MSG brightness temperatures in 6 channels TB (MSG)

↓ **Compare with measurements**

TB(NWP) – TB(MSG) : The temperature differences are used to change the initial profile, $T^n(p)$, $q^n(p)$

Retrieval Concept (1)

- **Updated** temperature and humidity profile: $T^n(p)$, $q^n(p)$

↓ **Radiative transfer model**

Expected MSG brightness temperatures in 6 channels TB (MSG)

↓ **Compare with measurements TB**

TB(NWP) – TB(MSG) : The temperature differences are used to change the initial profile

Retrieval Concept (1)

In every iteration of this process we check:

Is (TB(NWP) – TB(MSG)) small?

If yes, the process is stopped and the last profile is taken as the “best” solution

- MSG channels 5,6,(WV) 7,9,10 and 11 (IR) are currently used for calculations
- The GII product consists of a *set of instability indices* which describe the layer stability of the atmosphere:
  - K index,
  - Lifted Index,
  - Precipitable Water
  - KO Index
  - Maximum Buoyancy
- The retrieval of these parameters from satellite data is only possible under cloud-free conditions.

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Lifted Index

> 0	Thunderstorms unlikely
0 - -2	Thunderstorms possible – triggered needed
-3 - -5	Thunderstorms probable
-5 - -7	Strong/severe thunderstorms. Tornadoes possible

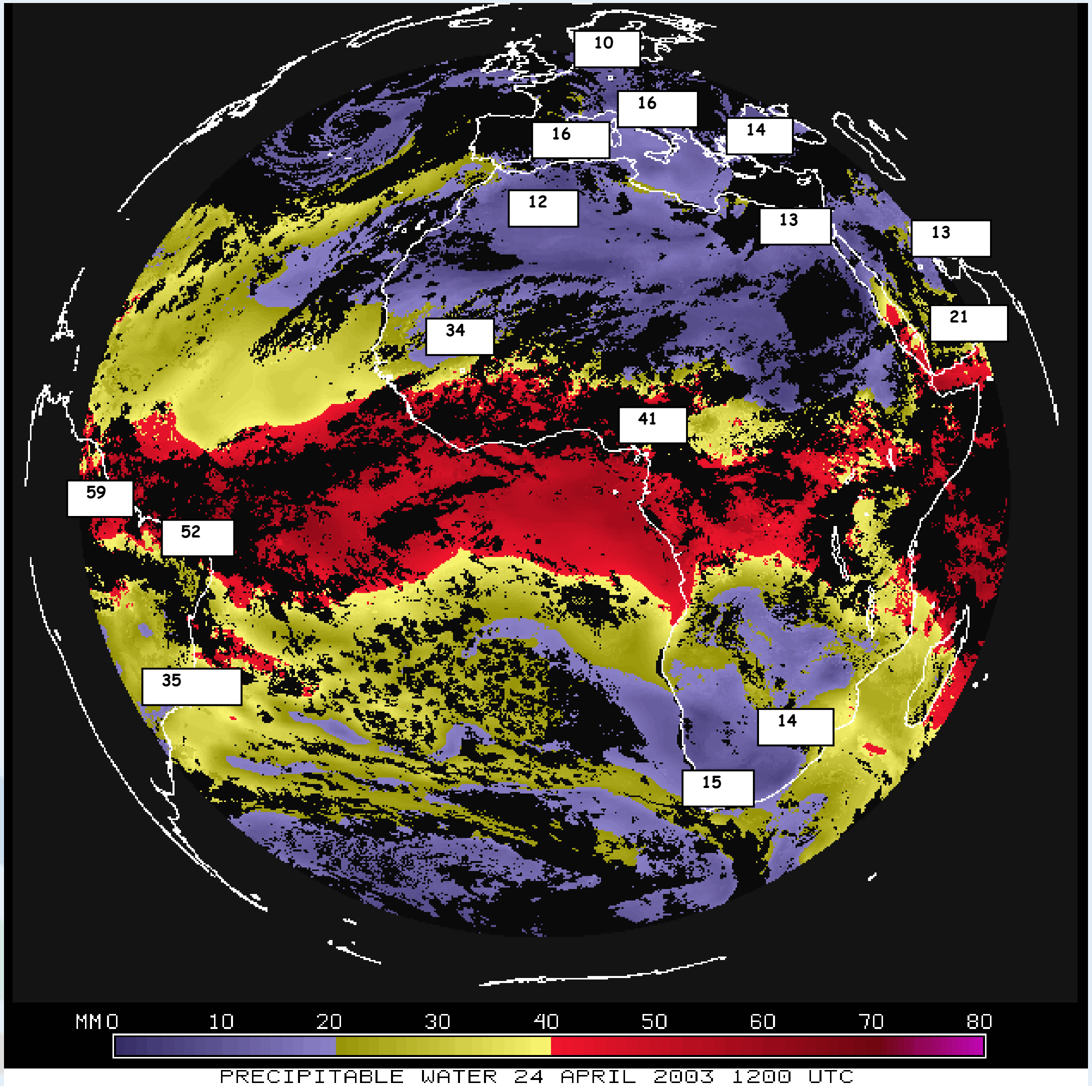
Sturtevant (1995)

K-Index

0 – 15	No thunderstorms
16 – 19	Thunderstorms unlikely
20 – 25	Isolated thunderstorms
26 – 29	Widely scattered thunderstorms
30 – 35	Numerous thunderstorms
36 – 39	Thunderstorms very likely
40+	100% chance of thunderstorms

Sturtevant (1995)

MSG MPEF Product: Global Instability Index GII



Satellite based instability Indices can be calculated every 15 minutes, in cloud free areas

Example of a total precipitable water retrieval, co-located radiosonde observations are also shown

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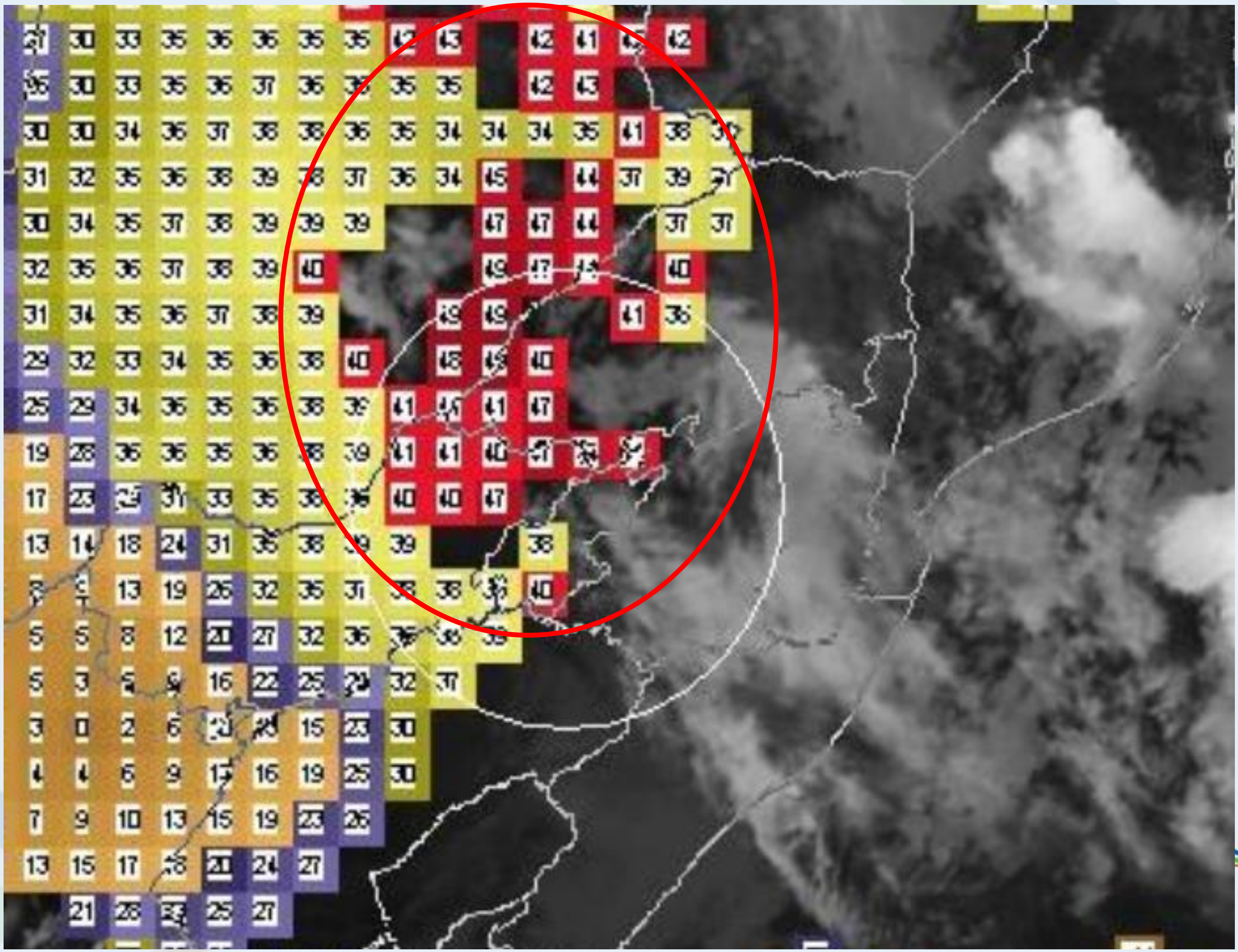
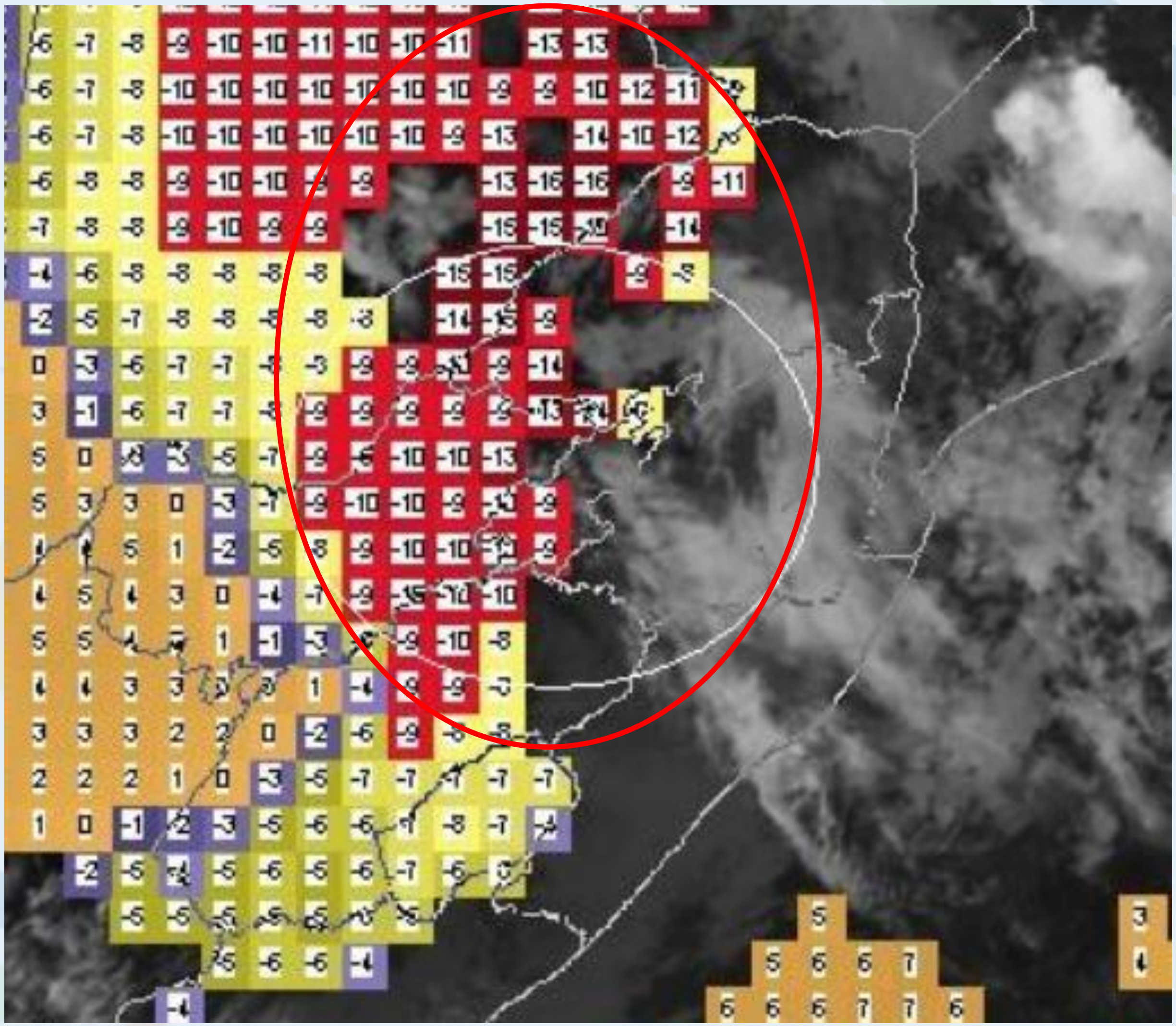
Example 1: 17 Jan 2007

- Early in the evening of Wednesday the 17th a large, severe line storm developed over southern Gauteng, south-western Mpumalanga and eastern North-West, moving into the greater Johannesburg area.
- Rainfall totals were up to 25 mm in these areas.
- Wind damage occurred in places and large hail was reported.
- Very large advertising signboards were dislodged by the wind at Ellis Park during a soccer match and players were injured.

GII K-Index at 06:00 GMT



GII L-index at 06:00 GMT



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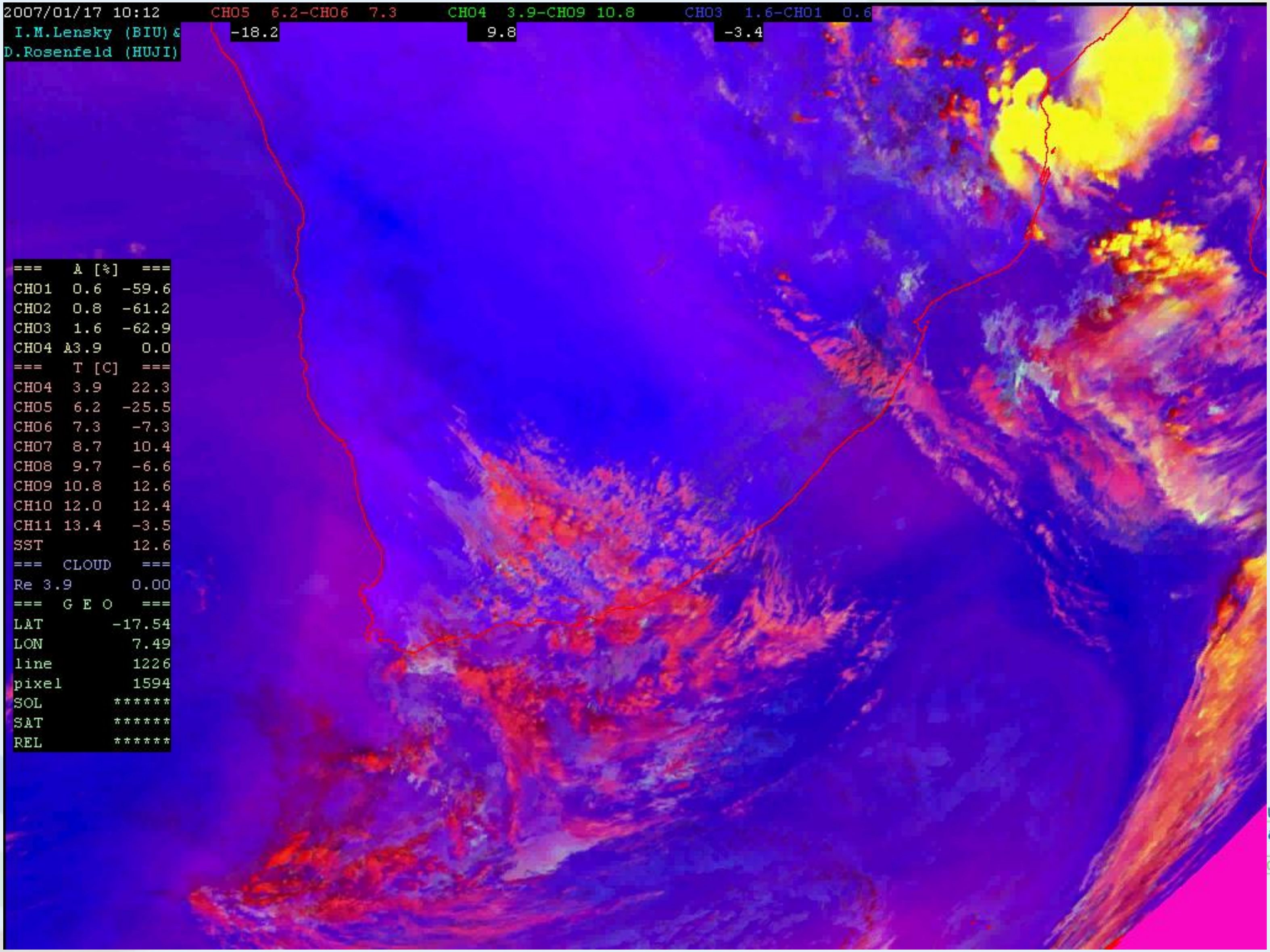
Conv RGB 1000-1500 UTC



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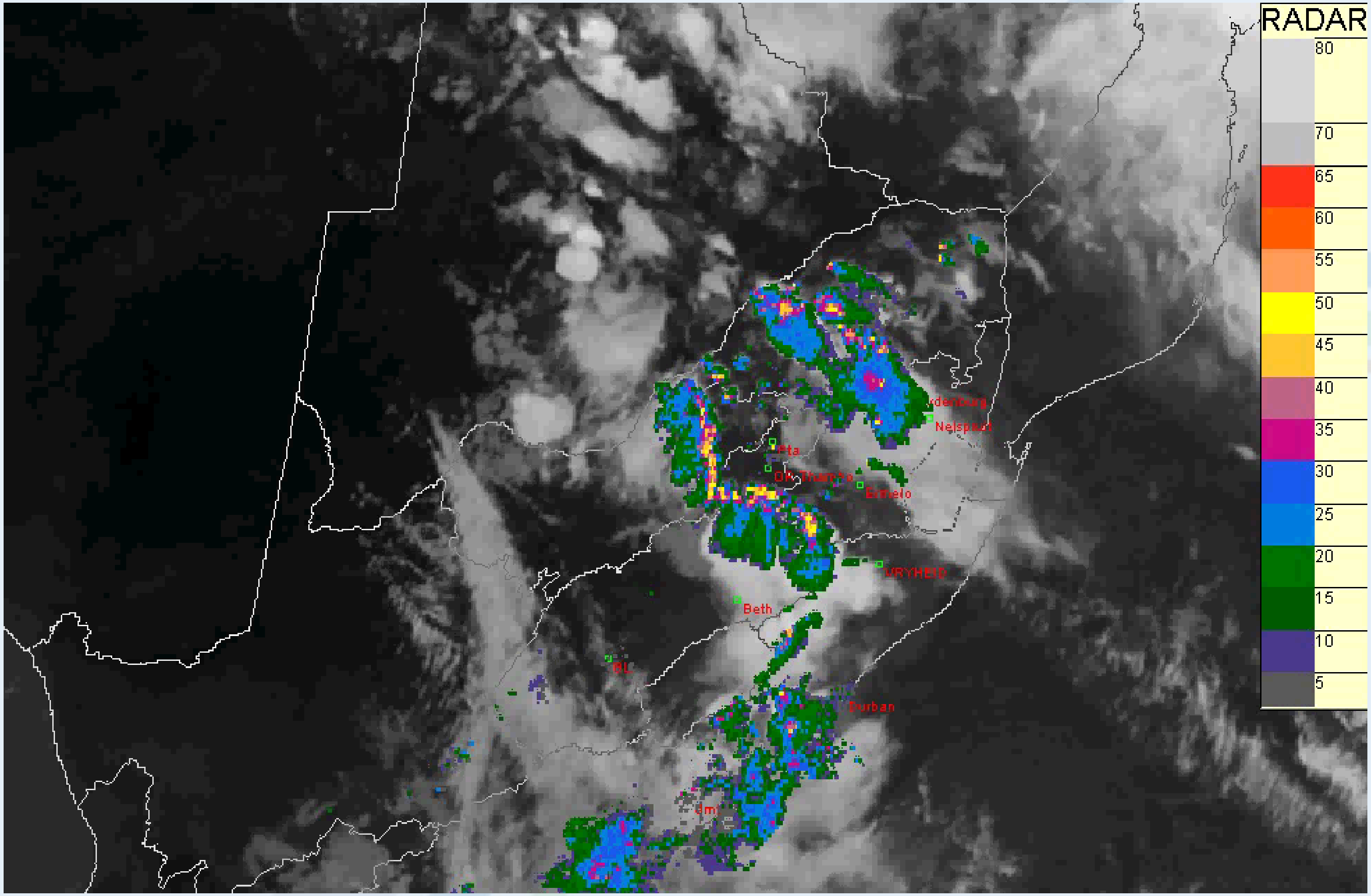
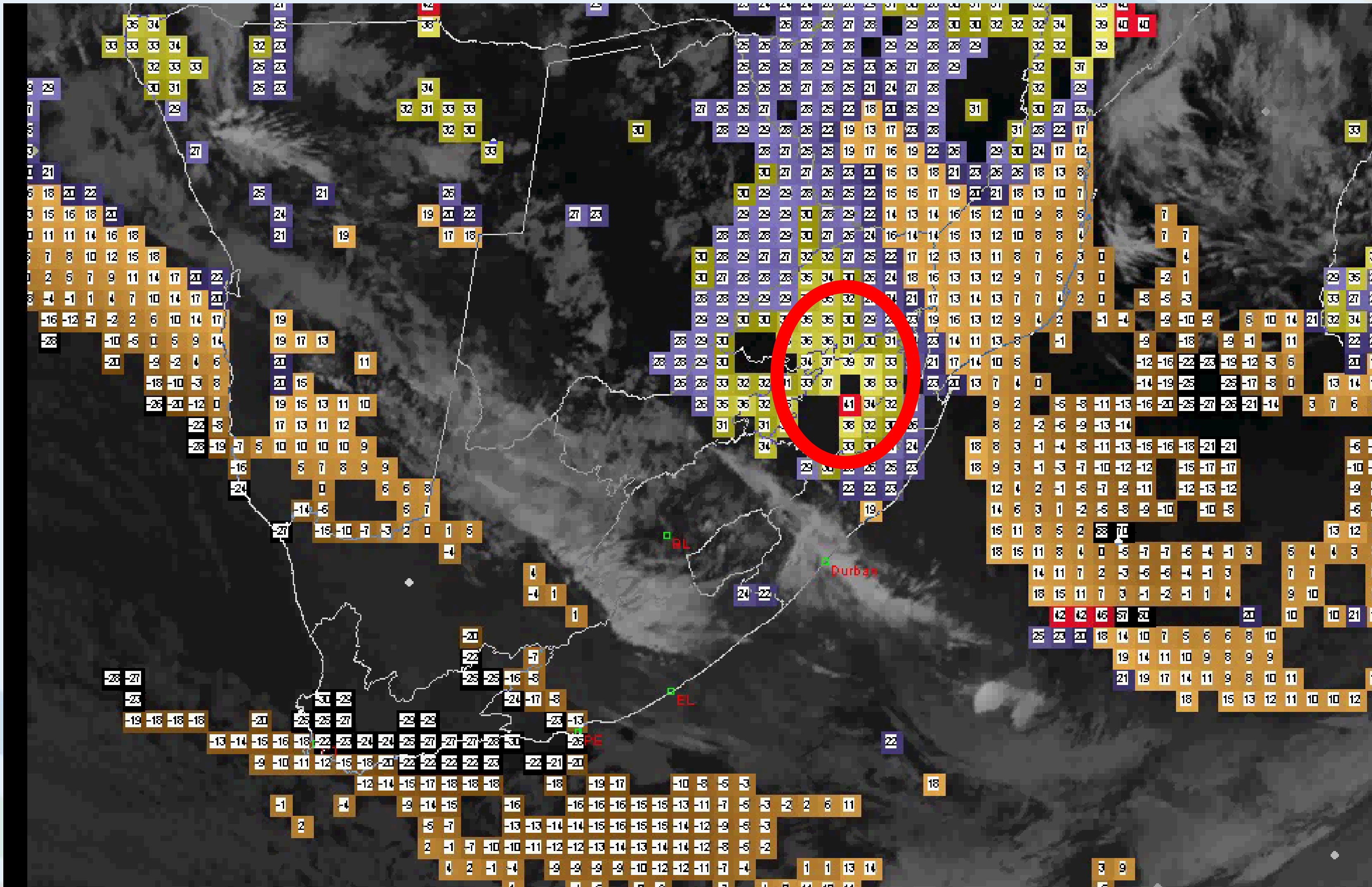


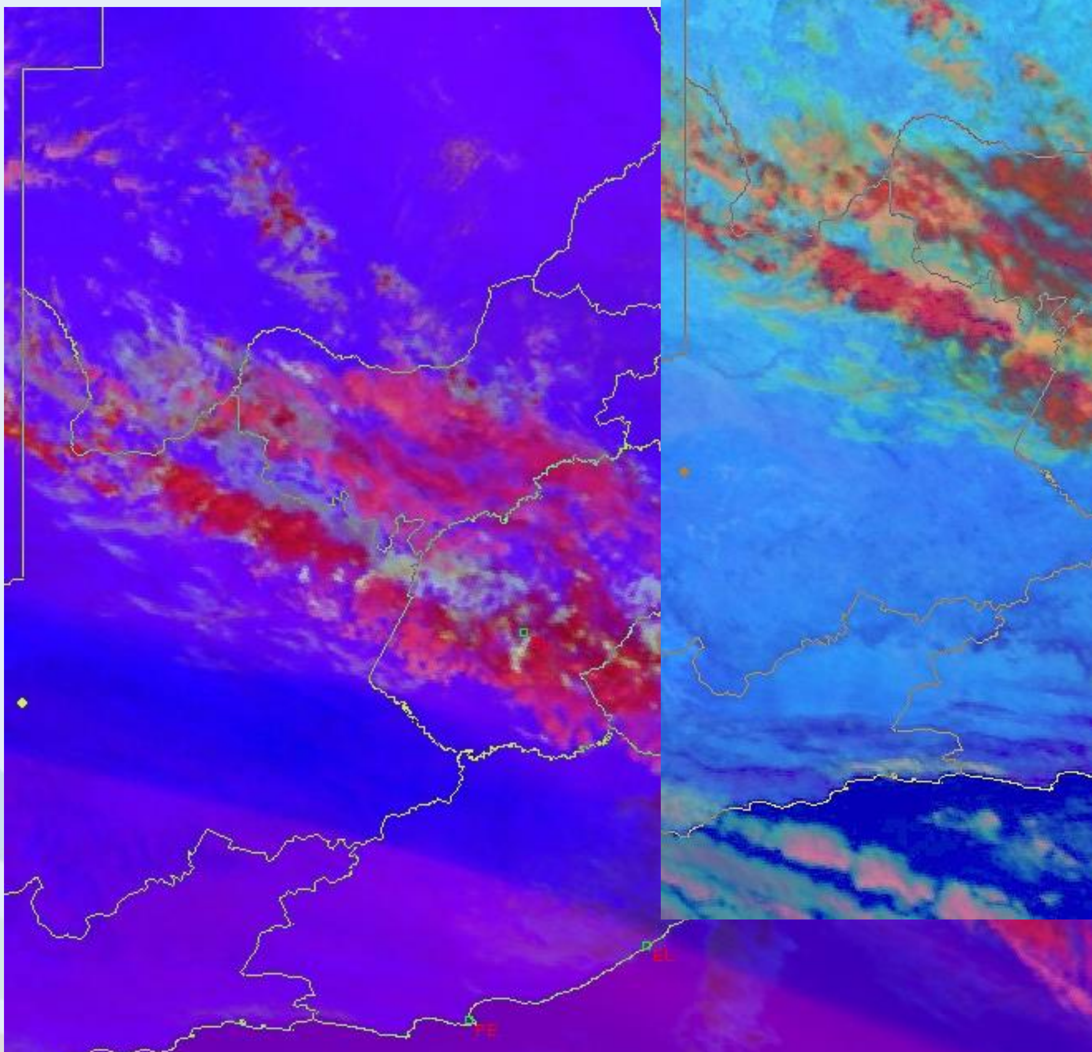
- Radar loop from 17:00 to 19:00 GMT every 15 min (overlaid with MSG IR10.8)

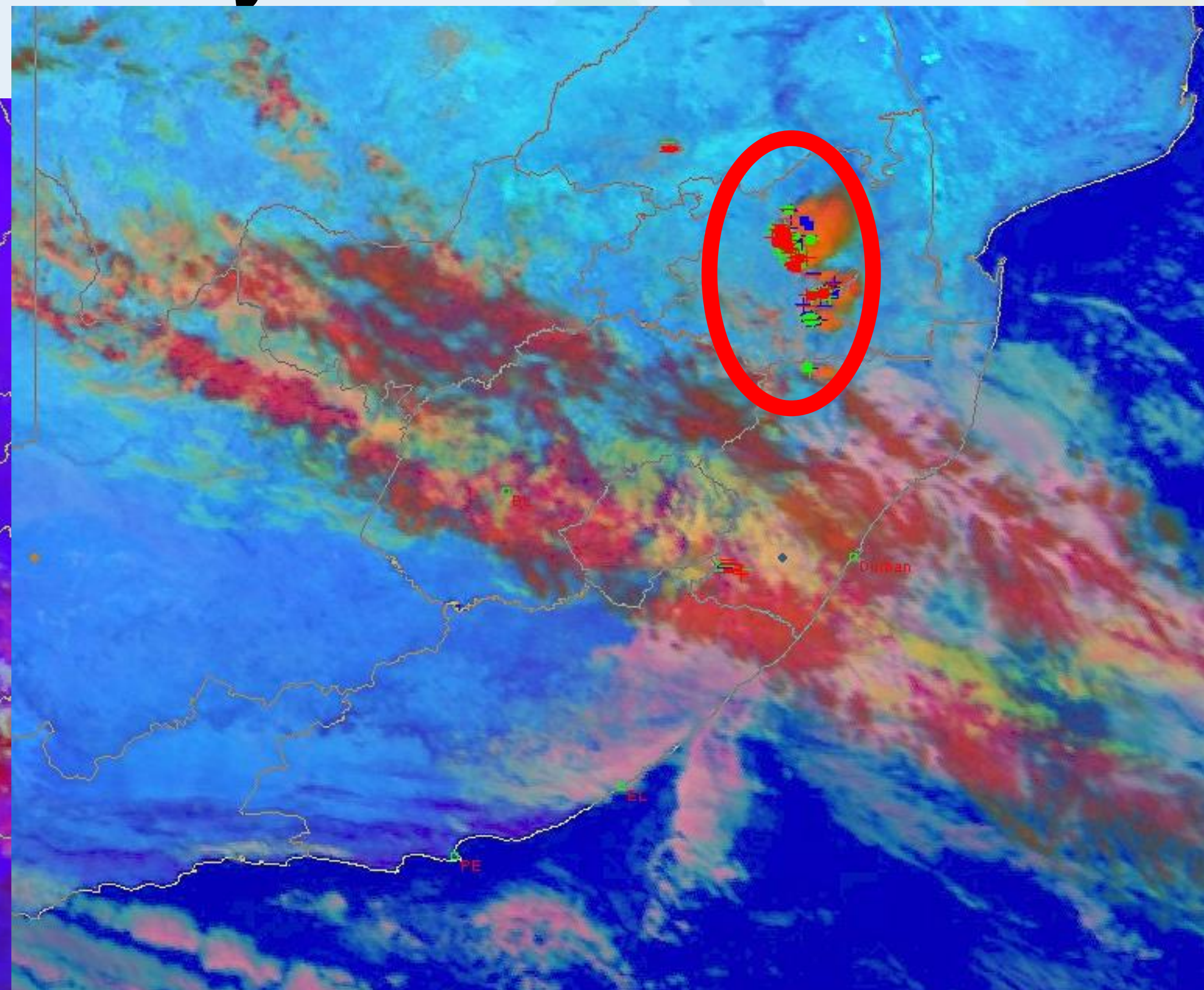
Example 2: 26 October 2007
KI between 0400 and 0800 UTC



Later that day….1030 UTC

Conv RGB





DayM RGB

Quantitative evaluation against lightning data

- GII Indices between 0400 and 0800 GMT
  - Lifted Index
  - K Index
- Lightning data between 1100 and 1800 GMT
- Thresholds:
  - Lifted Index has to be less than –5
  - K Index has to be more than 35
  - More than 5 lightning stokes have to occur in a 0.4X0.4 degree block

If the LI < -5 (or K index > 35) and more than 5 lightning strokes were recorded in that block, it is a correct forecast

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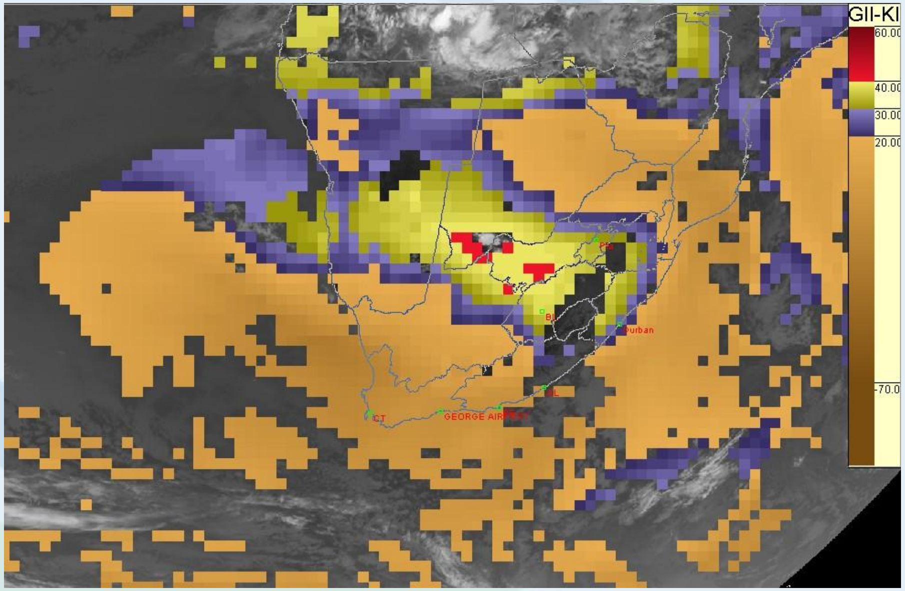
GII : Evaluation against lightning data: K index

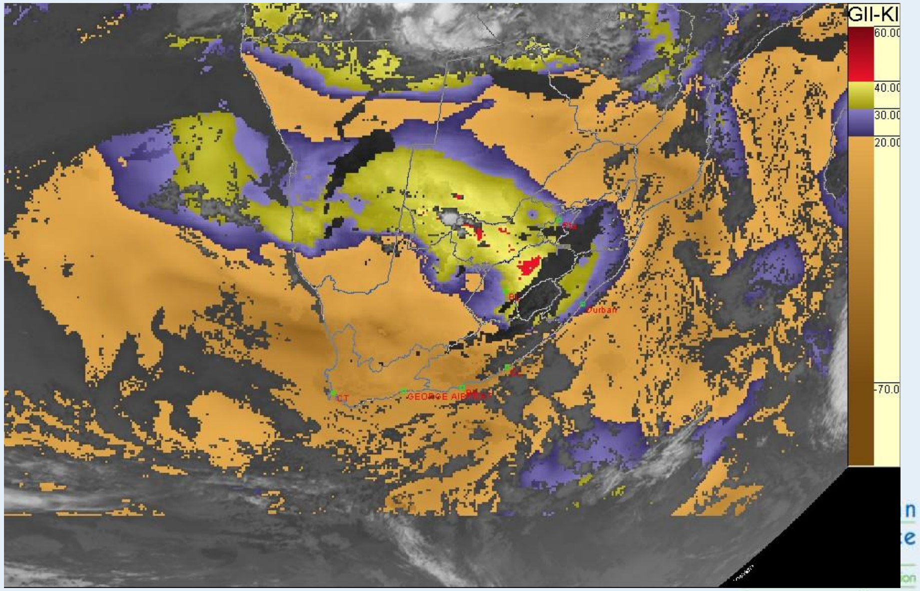
CASE	POD	FARatio
15 Jan 2007	0.47	0.31
16 Jan 2007	0.91	0.42
17 Jan 2007	0.73	0.33
28 Dec 2006	0.83	0.21
4 Mar 2007	0.93	0.38
6 Oct 2007	0.48	0.04
6 Nov 2007	1.0	0.13
4 Jan 2008	0.88	0.32
AVERAGE	**0.78**	**0.27**

Improvements using the Unified Model data

- Using local version of Unified Model (0.1° resolution) instead of ECMWF (1° resolution)
- Calculation of Lifted Index improved, Total Totals added
- Evaluation method refined to a finer resolution (0.1° in stead of 0.4° blocks)



GII - ECMWF



RII – Unified Model

A combined index

- Goal: to get one map, one parameter, in easy terms for a forecaster to use for very short range forecasting of thunderstorms
- Need for thunderstorms: instability, moisture and lift

The combined index (cont)

- Use KI, PW, LI and TT and for each of them:
  - Verify the parameter in the early morning against the occurrence of lightning later in the day with cumulative frequency tables
  - Compile a “look-up” table… where a value of the index corresponds to a percentage chance that lightning occurs at that value

Lookup tables…

	Feb Ave	Mrch Ave	Jan Ave	Nov Ave	Dec Ave	Ave
>=2	1.58	4.65	1.23	3.70	2.93	2.7
<2	4.20	11.20	2.53	11.43	6.13	7.2
<1	10.82	19.95	8.03	22.20	11.40	14.8
<0	19.80	30.30	18.77	34.52	21.88	25.5
<-1	30.44	44.50	31.43	52.67	35.68	39.7
<-2	41.60	59.80	44.87	65.45	49.80	52.7
<-3	62.42	76.55	61.10	76.72	59.30	67.3
<-4	80.78	90.85	74.80	86.10	68.93	80.1
<-5	92.00	98.15	85.97	90.82	78.20	88.6
<-6	97.08	99.80	92.87	95.53	86.70	94.2
<-7	99.02	100.00	96.67	97.97	93.98	97.4
<-8	99.74	100.00	98.87	99.38	98.58	99.3
<-9	99.94	100.00	99.83	99.87	100.00	99.9
<-10	99.94	100.00	99.97	99.97	100.00	100.0
<-11	100.00	100.00	100.00	100.00	100.00	100.0

CII definition…..

- For Total Totals, K Index, Lifted index and Precipitable Water:
  - Percentage chance of seeing lightning from look up tables
  - Weighted with HK/TSS
  - And normalized and adding up to 80% of CII
- Topography:
  - Percentage change of seeing lightning from topography the other 20%
- CII = 80% from instability and atmospheric moisture and 20% from trigger due to topography
- CII validation was done comparing it to lightning occurrence in the following 12 hours.

CII validation

- Using area where CII>10%:
  - POD 99%
  - Hanssen Kuiper 81%
- Using area where CII>30%:
  - POD 75%
  - Hanssen Kuiper 0.66%

World Meteorological Organization

Regional Specialised Meteorological Center (RSMC) Pretoria

Designated to South African Weather Service

Guidance Products

NWP & EPS Products

Regional Models

- UM SA12
- UM Africa LAM
- Aladin La Reunion

Global Products

- NOAA: GFS
- ECMWF: EPS
- Met Office: EPS
- NOAA: EPS
- SAWS: EPS (SAWS)

Training Website

- Met-eLearning

RSMC Guidance Archive

Contact RSMC

Logout

Guidance Products

Short-range (1-2 Days)

- Map Day 1
- Map Day 2
- Risk Tables
- Discussion

Medium-range (3-5 Days)

- Map Day 3
- Map Day 4
- Map Day 5
- Prob Tables
- Discussion

SWFDP Evaluation Form

- Click Here

Satellite-based 0-12 Hour Products

Satellite-Based Rainfall

Hydro-Estimator Rainfall Totals

- 1hr
- 3hr
- 6hr
- 24hr

Hydro-Estimator Rainfall Totals In Days

- 10 Days
- 30 Days
- Description of Product

Convective Thunderstorm Forecasts

Probability of Convective Thunderstorms

- CII
- Description of Product

Hydro-estimator Storm Tracks

SADC
SADC NW
SADC NE
SADC SW
SADC SE
Madagascar
South Africa

Regional and International Centers

- ECMWF
- NCEP
- UK Met Office
- WMO
- RSMC - Reunion
- ACMAD

SADC Countries

- SADC Countries National Meteorological Services

Other Services and Products

- Short-range
- Long-range (Seasonal)

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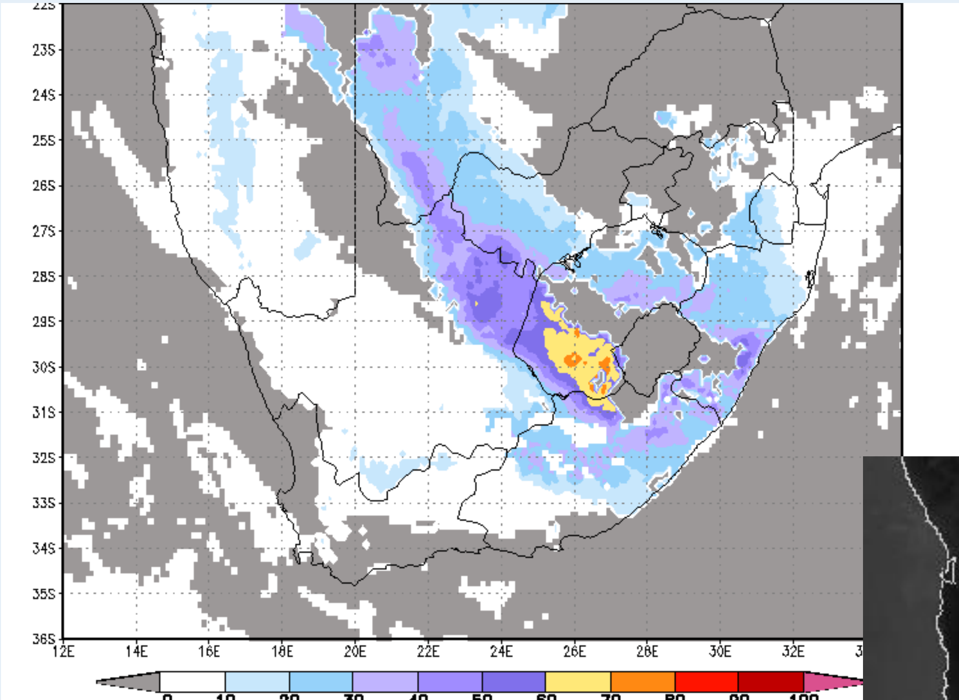
Examples

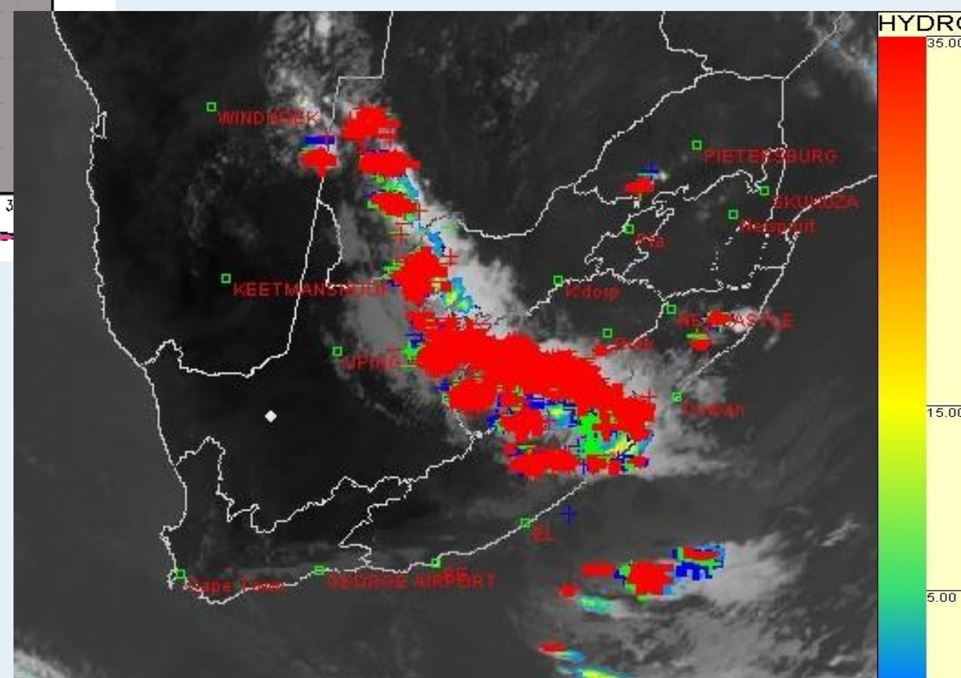
CII vs lightning later in the day

31 Jan 2010



CII 06:00-0900 UTC

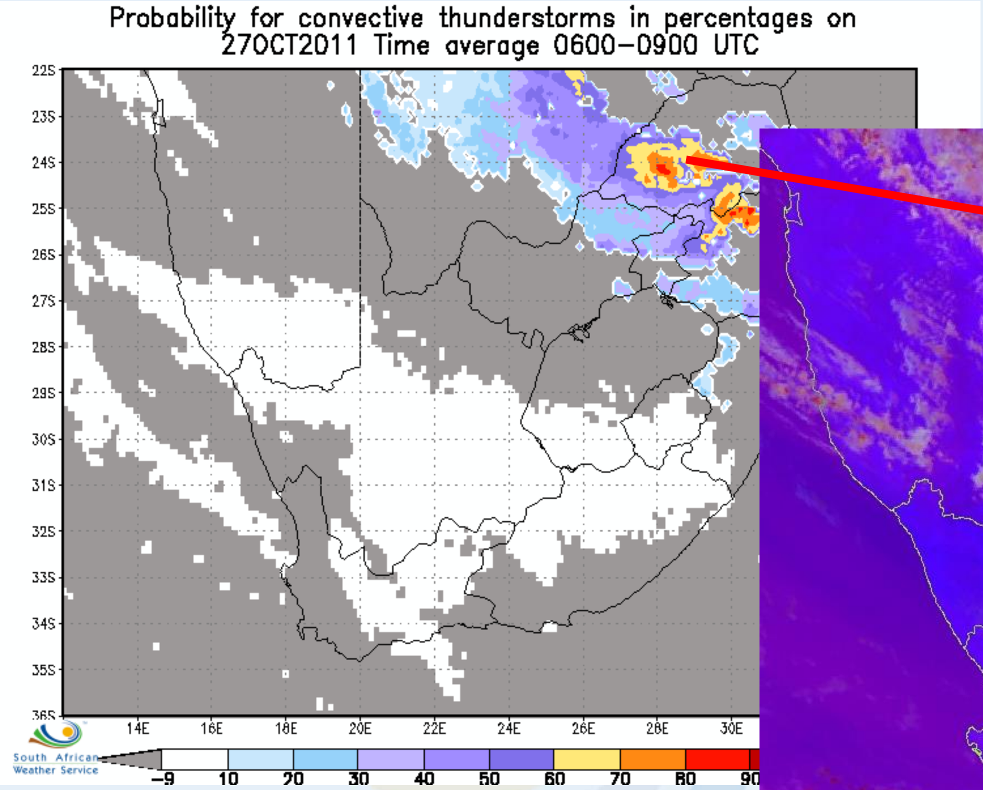
1500 UTC



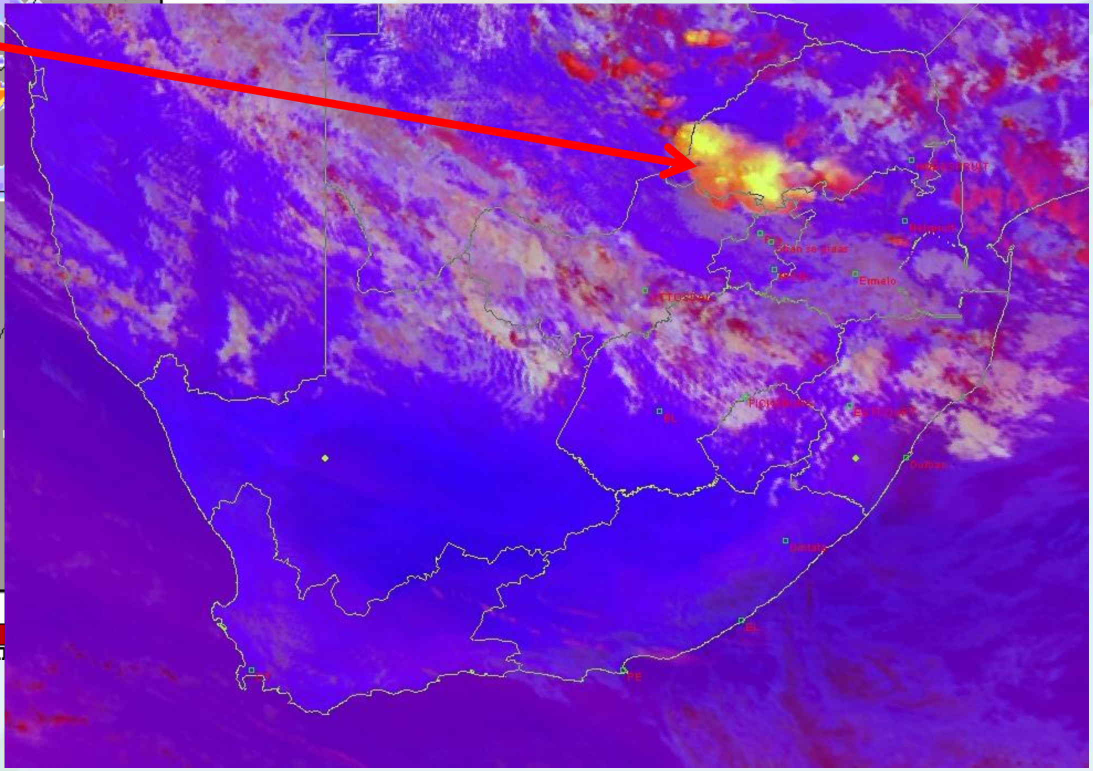
To cover as many pixels as possible, use time average early in the morning 0600 to 0900 UTC

CII vs Convection RGB

Example 27 Oct 2011

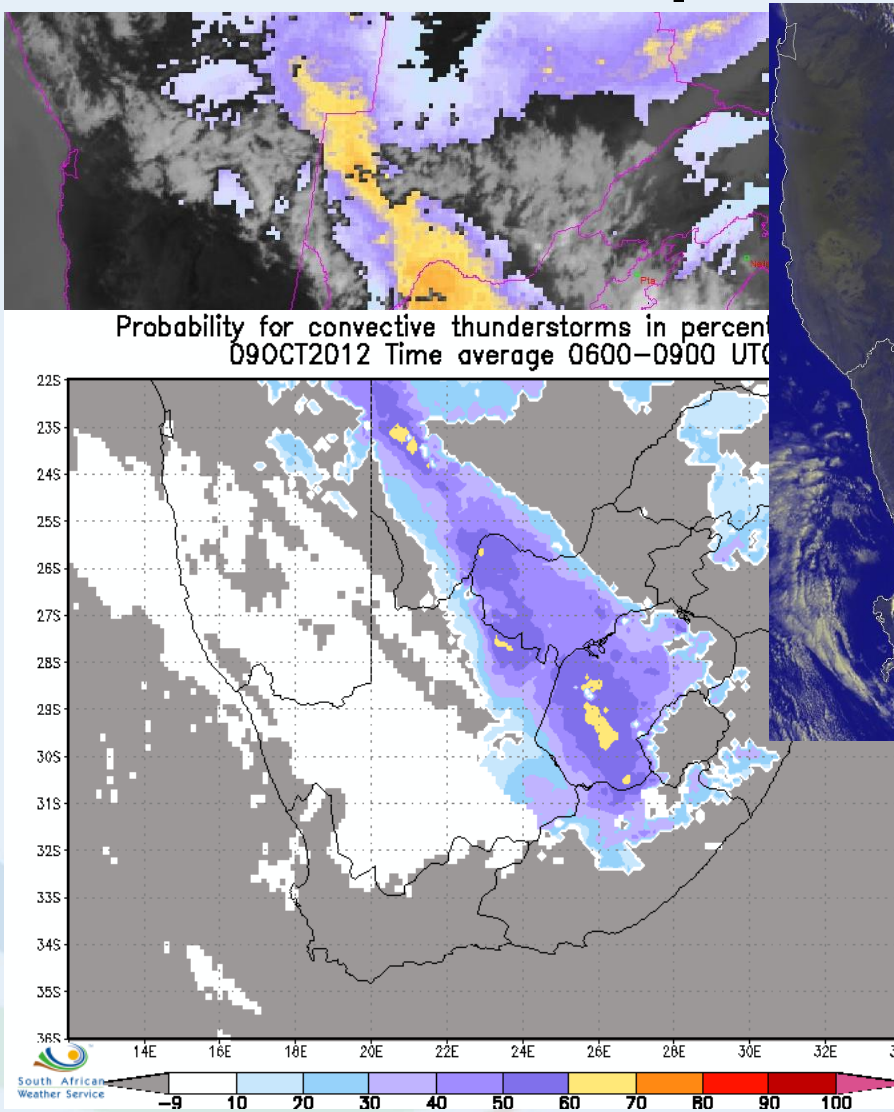


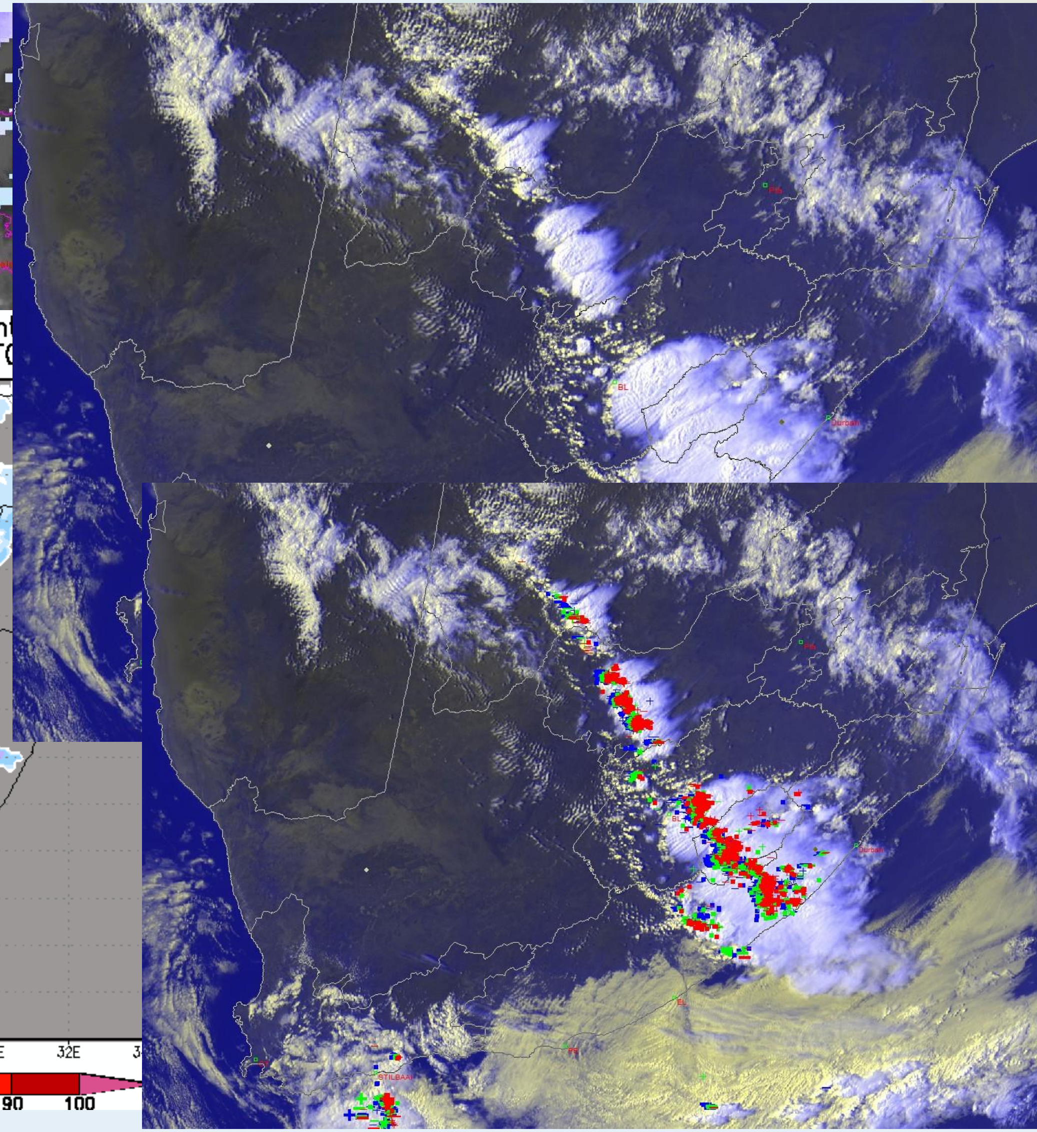
Conv RGB 1330 UTC



CII vs HRV RGB and lightning

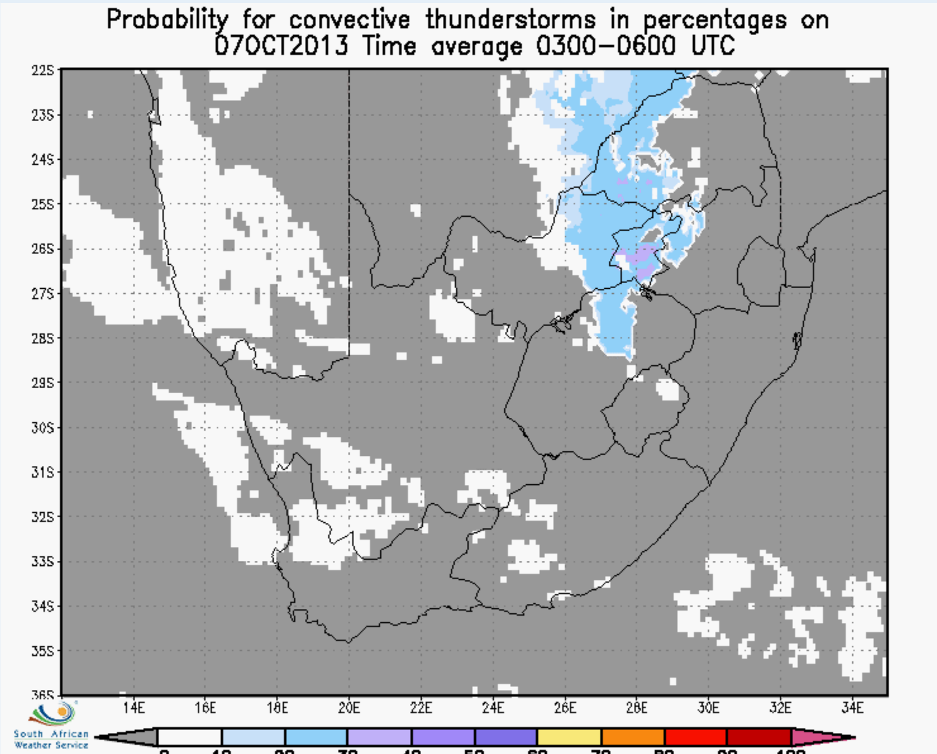
Example: 9 Oct 2012





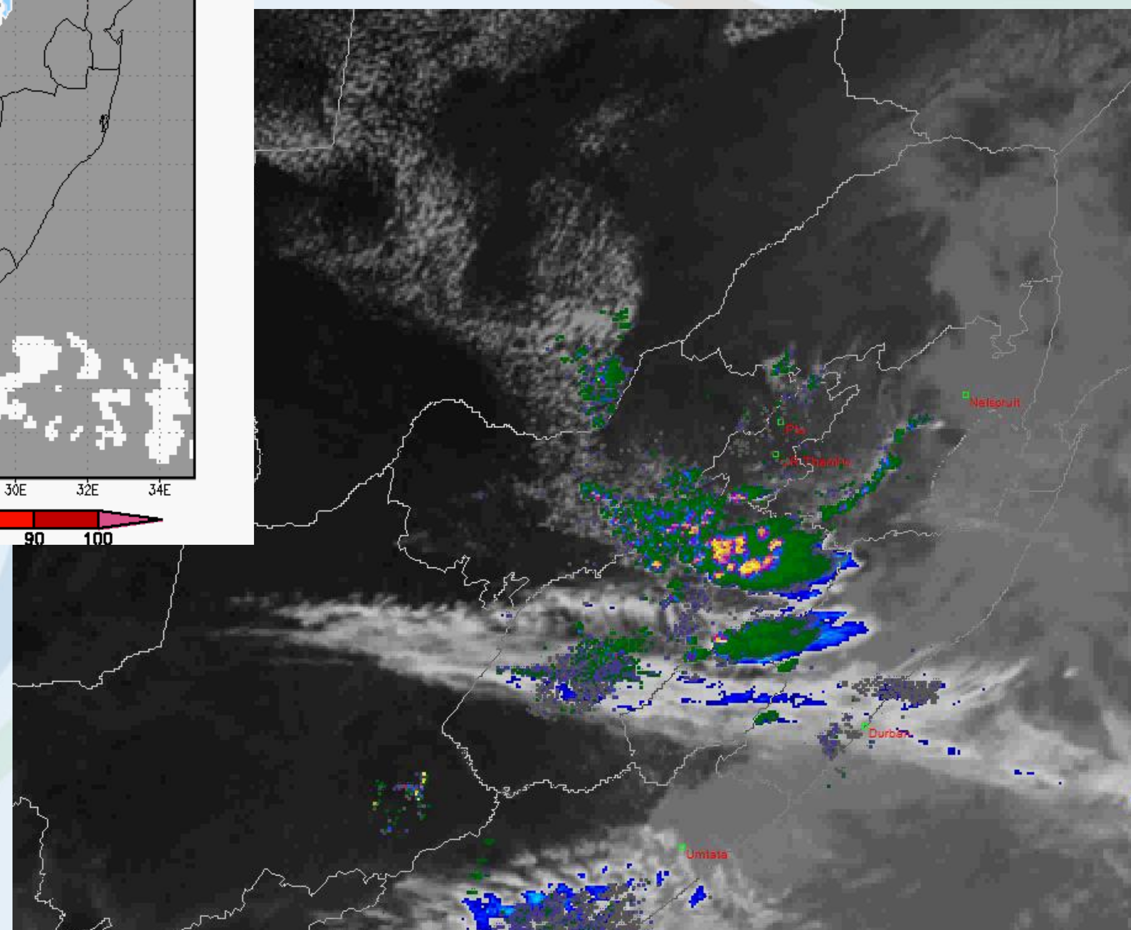
CII vs MSG and radar

CII vs MSG and radar



CII time averages from 0300-0600 up to 1000 UTC

MSG with radar 1200 – 2000 UTC



CII vs colour enhanced IR over SADC

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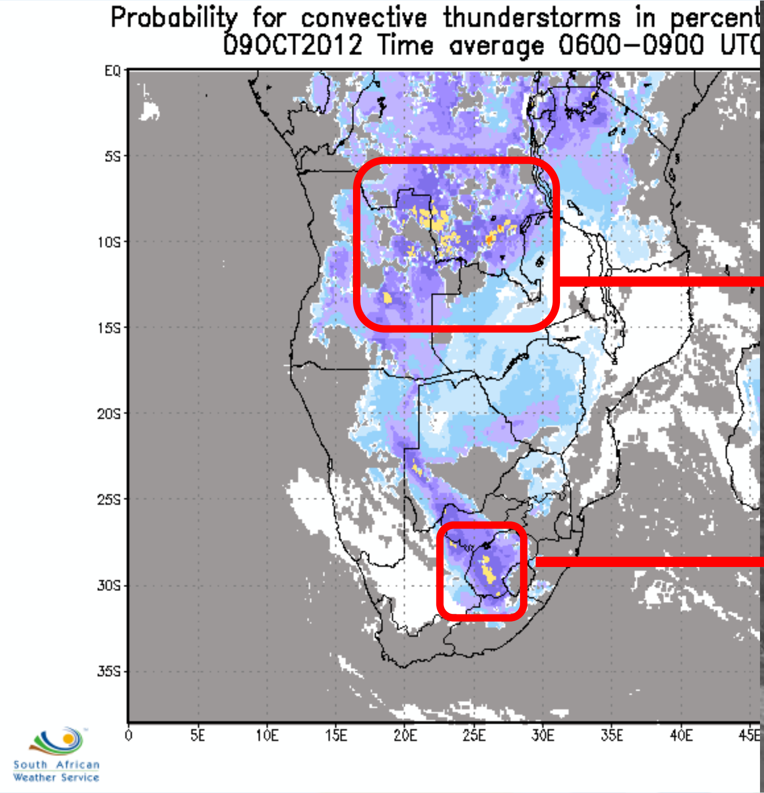
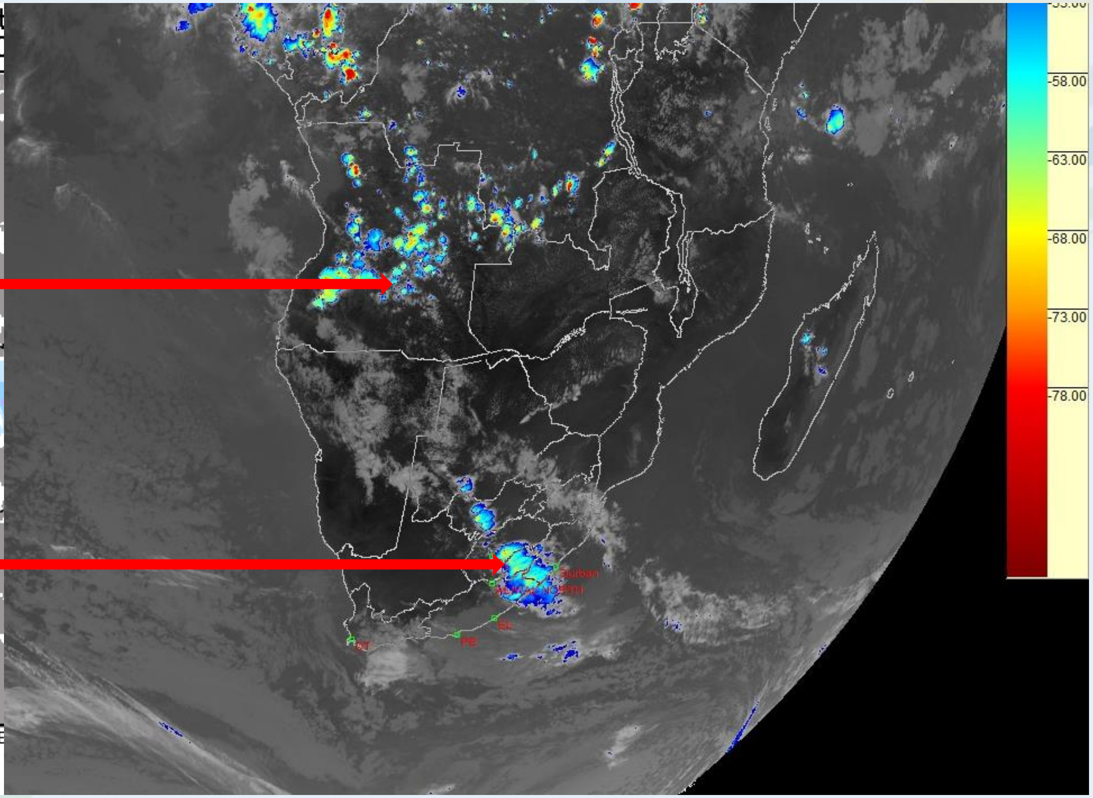
Example 9 Oct 2012





IR Colour enhanced 1400 UTC

CII vs Hydroestimator over SADC

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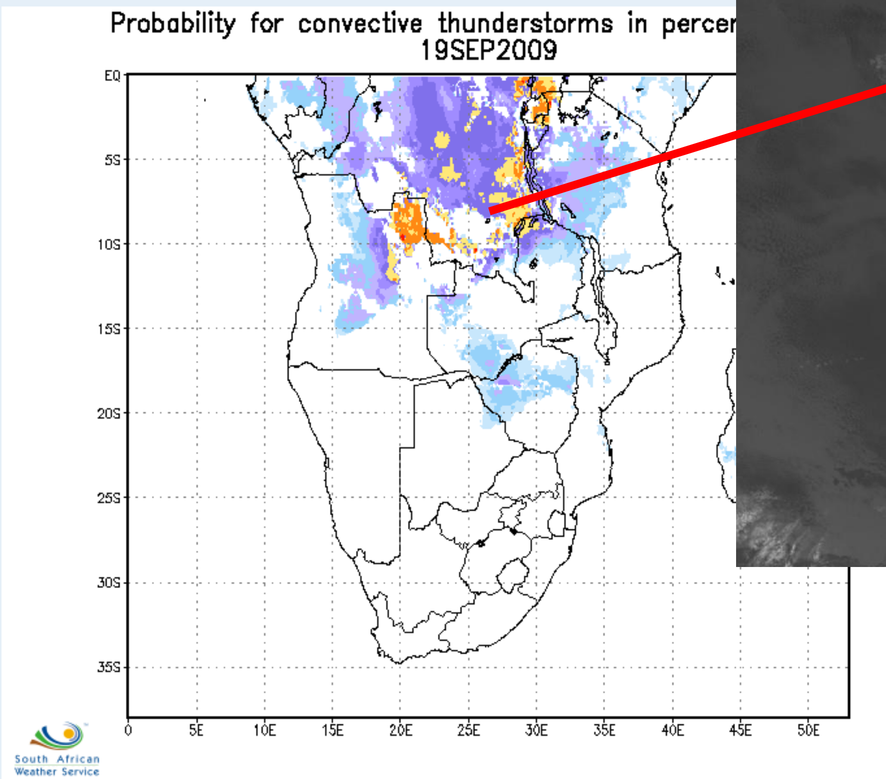
CII vs HE



Probability for convective thunderstorms in percen
19SEP2009
EQ
5S
10S
15S
20S
25S
30S
35S
0
5E
10E
15E
20E
25E
30E
35E
40E
45E
50E
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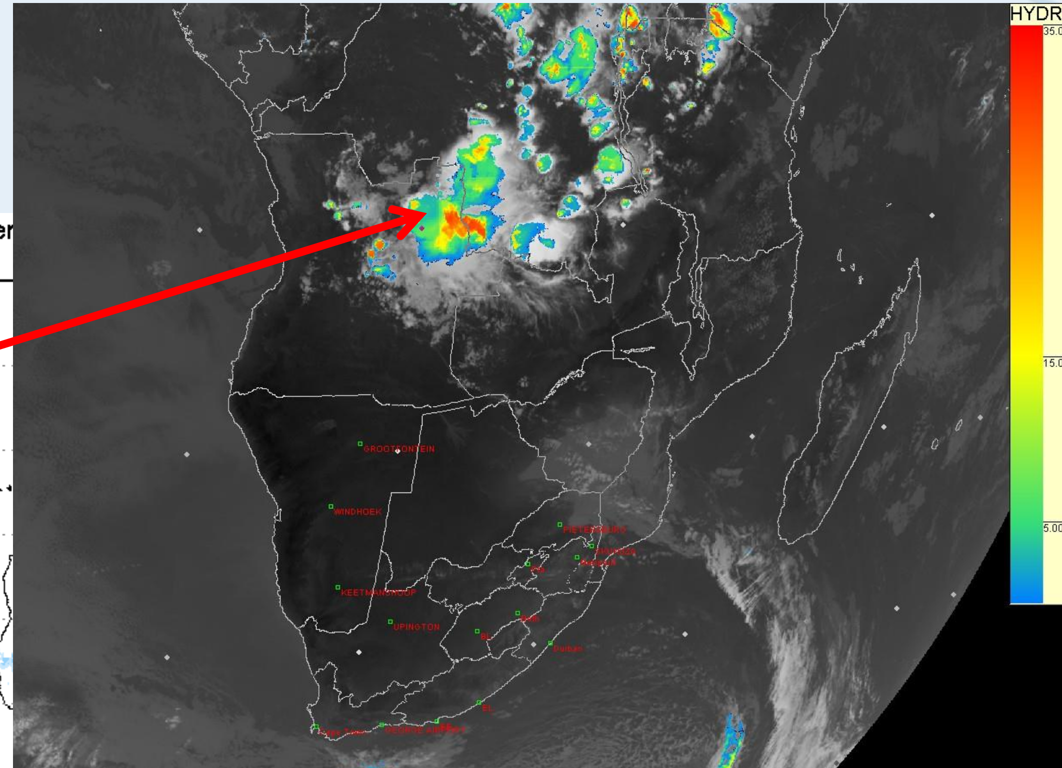
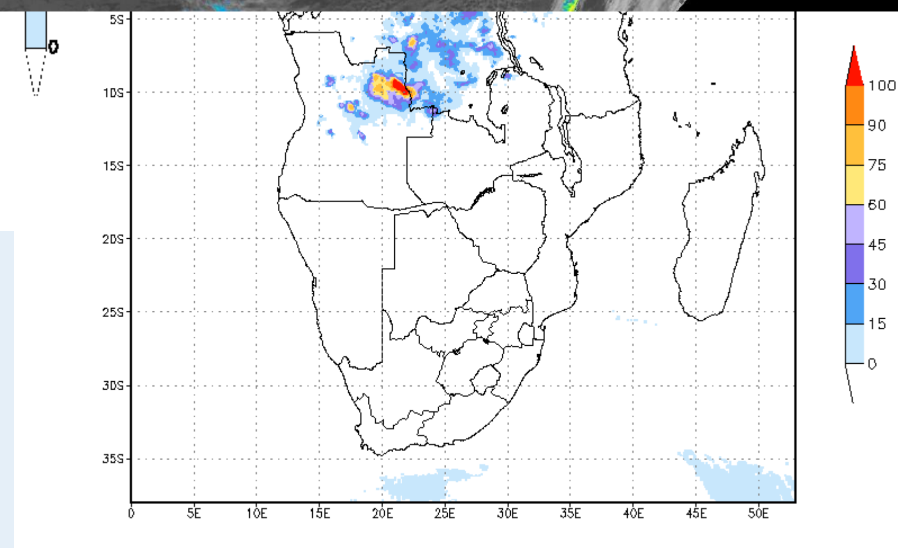


HYDRO
35.00
15.00
5.00
GROOTFONTEIN
WINDHOEK
KEETMANSHOOP
UPINGTON
Durban



5S
10S
15S
20S
25S
30S
35S
0
5E
10E
15E
20E
25E
30E
35E
40E
45E
50E
100
90
75
60
45
30
15
0
GrADS: COLA/IGES
2009-09-20-07:02

CII vs WWLLN for SADC

- Previous studies of WWLLN network to determine detection efficiency:
  - DE is very low – few percent of total lightning
  - DE vastly different for different places

- Reasons for discrepancies:
  - WWLLN receiver distribution = sparse and not uniform
  - Number of sensors increased during different evaluation phases
  - Diversity in networks used as ground truth in different countries – each has own limited DE
  - Each study conducted on different time scales and area sizes

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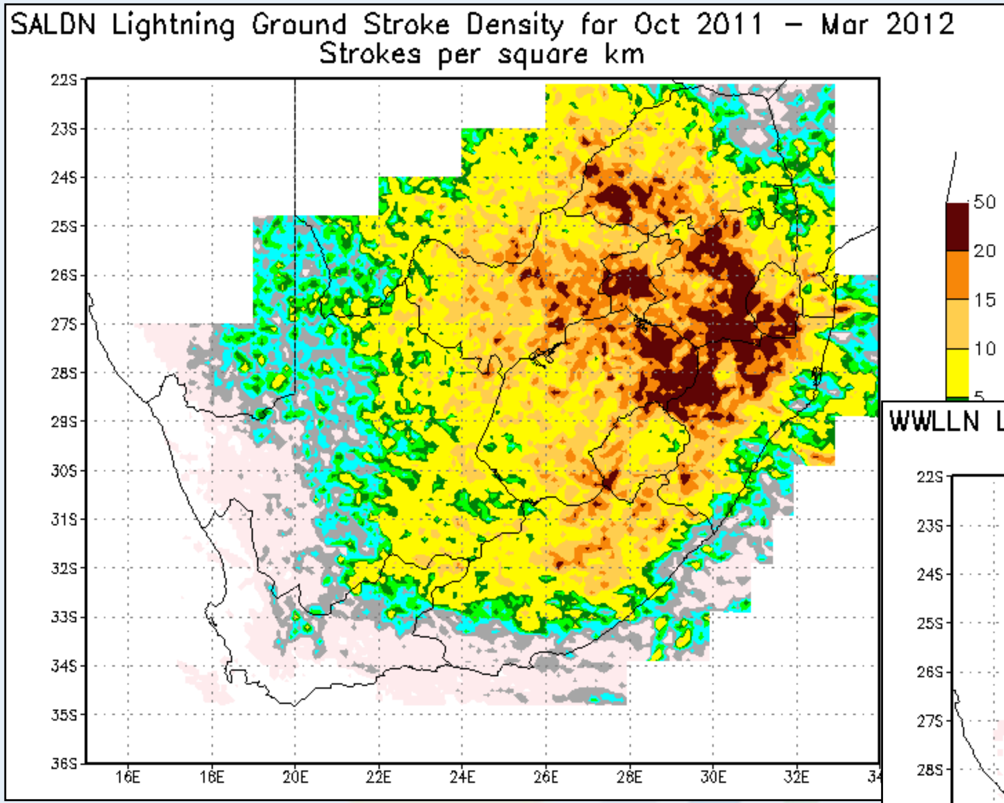
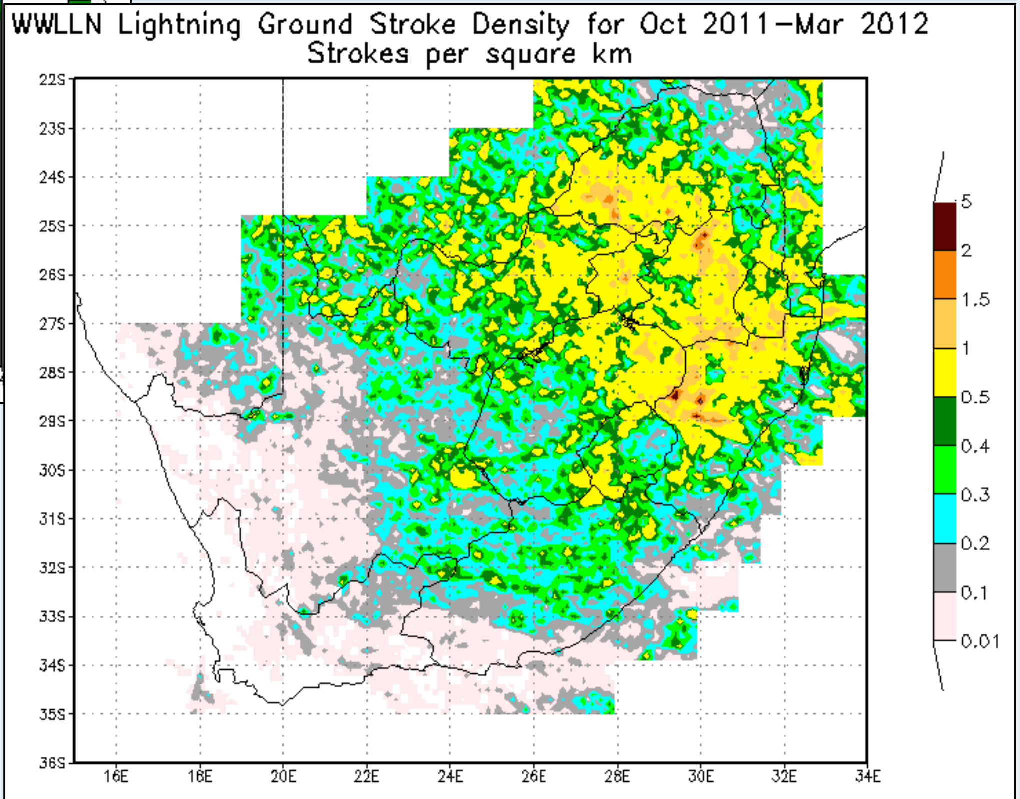
Slide courtesy Cassandra Pringle

Detection efficiency Vaisala ground network vs WWLLN

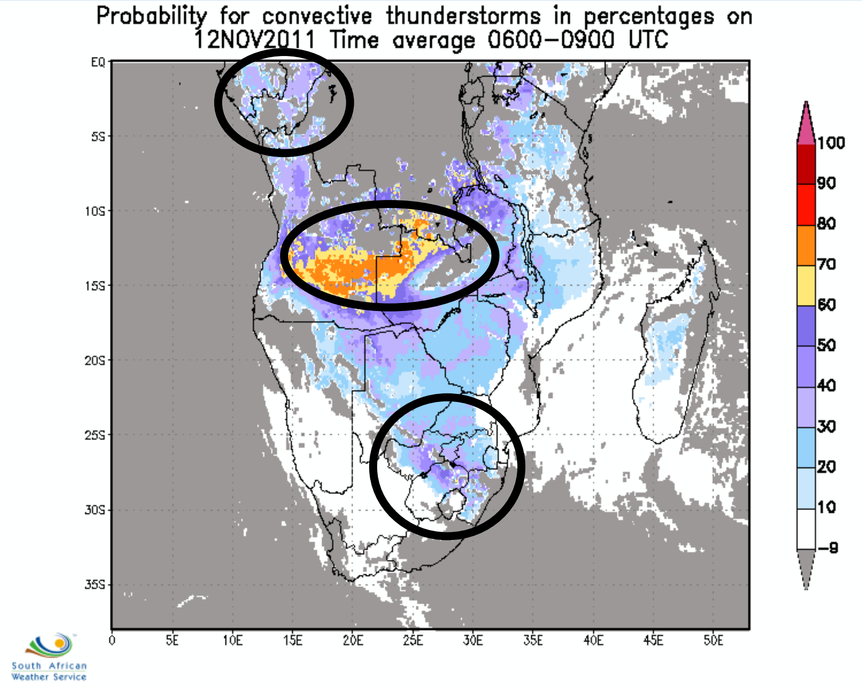


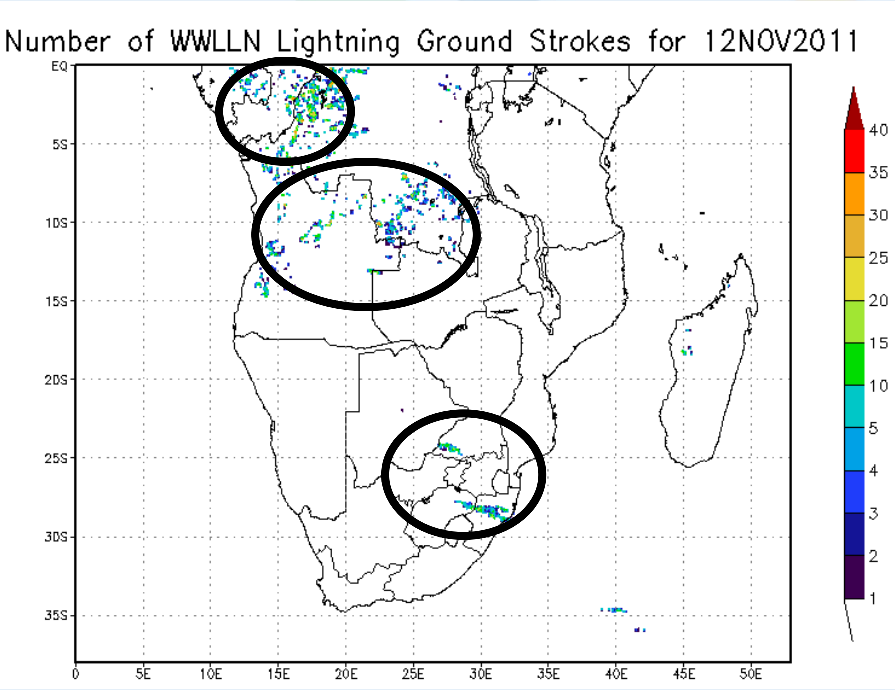
SALDN groundstroke densities:
1 to >50 strokes/km^2



WWLLN ground stroke densities:
0.1 to >5 strokes/km^2

Case 1: 12 November 2011





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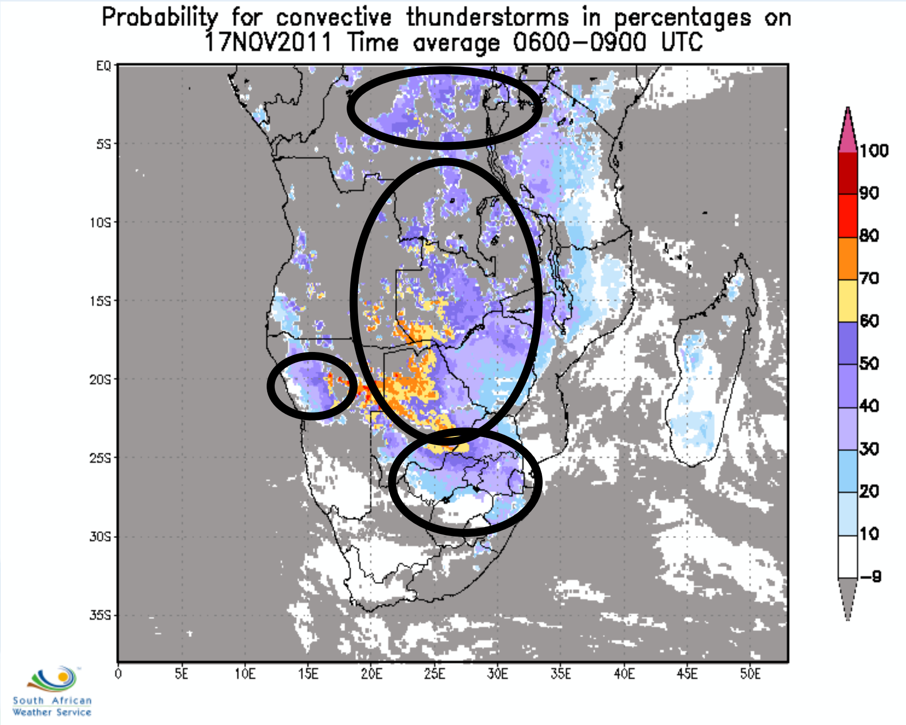
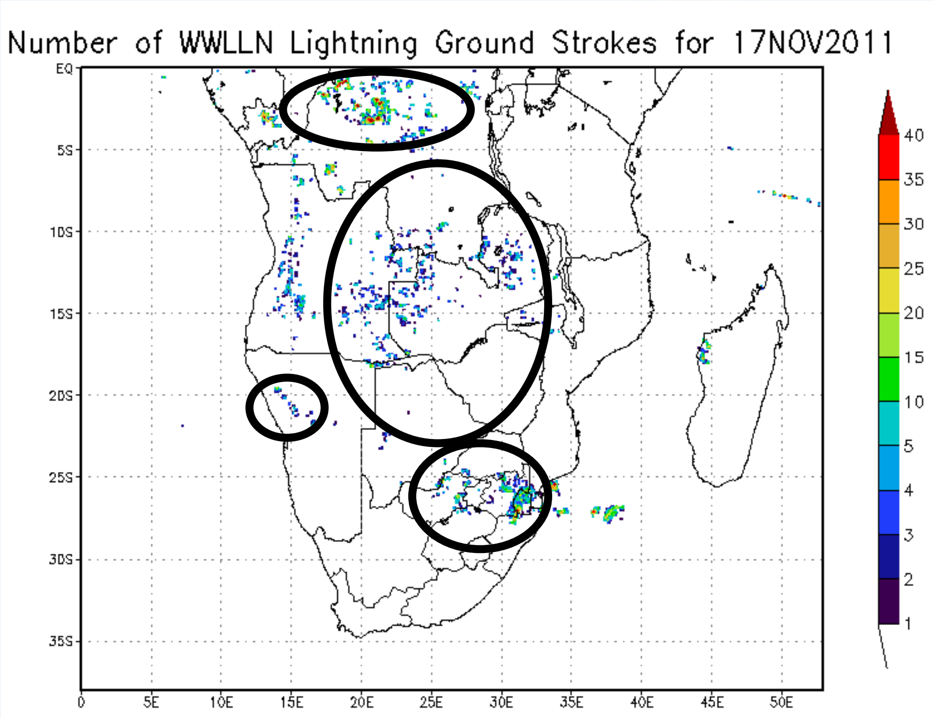
WWLLN data courtesy Cassandra Pringle

Case 2: 17 November 2011





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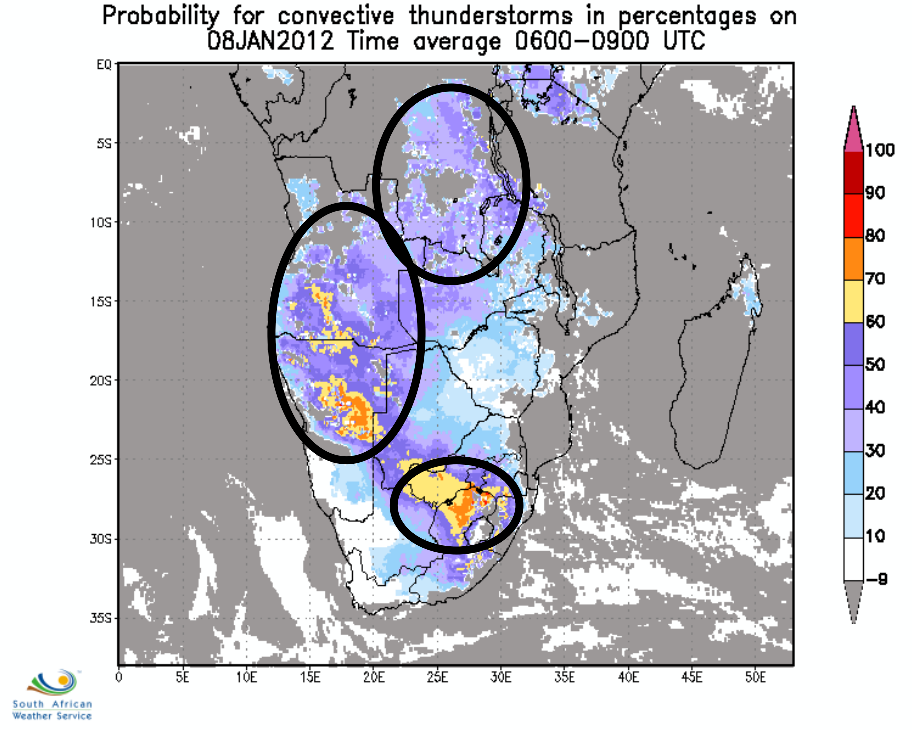
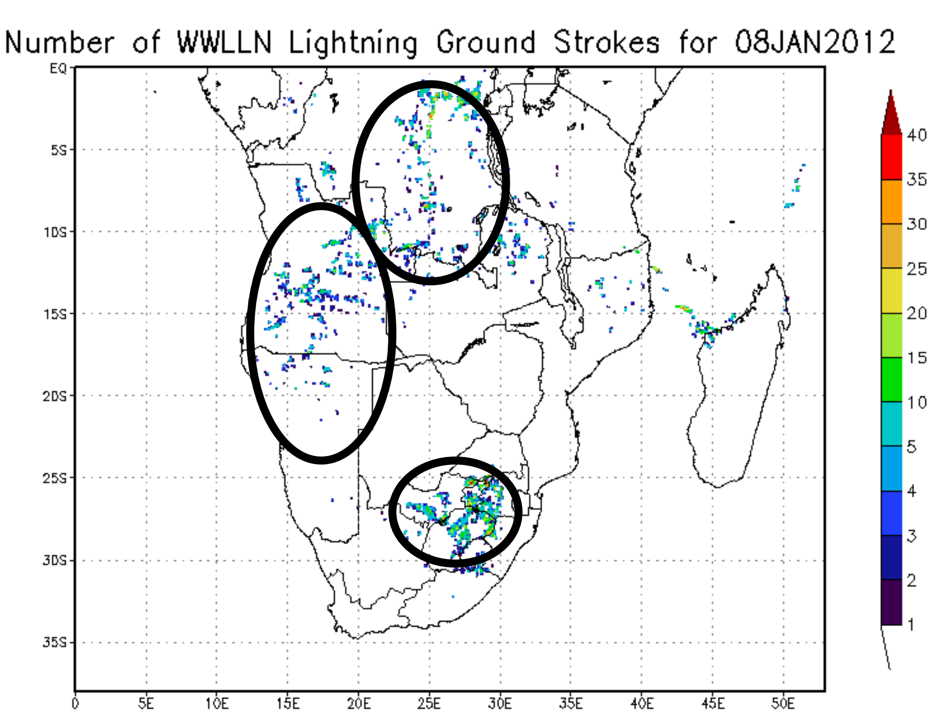
WLLN data courtesy Cassandra Pringle

Case 3: 8 January 2012





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Slide courtesy Cassandra Pringle

World Meteorological Organization

Regional Specialised Meteorological Center (RSMC) Pretoria

Designated to South African Weather Service

Guidance Products

NWP & EPS Products

Regional Models

- UM SA12
- UM Africa LAM
- Aladin La Reunion

Global Products

- NOAA: GFS
- ECMWF: EPS
- Met Office: EPS
- NOAA: EPS
- SAWS: EPS (SAWS)

Training Website

- Met-eLearning

RSMC Guidance Archive

Contact RSMC

Logout

Guidance Products

Short-range (1-2 Days)

- Map Day 1
- Map Day 2
- Risk Tables
- Discussion

Medium-range (3-5 Days)

- Map Day 3
- Map Day 4
- Map Day 5
- Prob Tables
- Discussion

SWFDP Evaluation Form

- Click Here

Satellite-based 0-12 Hour Products

Satellite-Based Rainfall

Hydro-Estimator Rainfall Totals

- 1hr
- 3hr
- 6hr
- 24hr

Hydro-Estimator Rainfall Totals In Days

- 10 Days
- 30 Days
- Description of Product

Convective Thunderstorm Forecasts

Probability of Convective Thunderstorms

- CII
- Description of Product

Hydro-estimator Storm Tracks

SADC
SADC NW
SADC NE
SADC SW
SADC SE
Madagascar
South Africa

Regional and International Centers

- ECMWF
- NCEP
- UK Met Office
- WMO
- RSMC - Reunion
- ACMAD

SADC Countries

- SADC Countries National Meteorological Services

Other Services and Products

- Short-range
- Long-range (Seasonal)

Advantages of CII:

- One map – in probabilities (not thresholds)
- Incorporates moisture (PW), instability (MK and MT) as well as a trigger mechanism (topography) – all the ingredients for convection to occur
- Combines MSG and NWP in real time (15 min)
- Developed based on occurrence of lightning (as verification of convection)
- Good correlation with lightning occurrence in the 12 hours following the CII time
- CII outperformed the individual parameters ("ensemble" principle)
  - Publication on GII in AMS bulletin (USA) Feb 2009.
  - Publication on RII and CII published in Met Applications (UK) in 2011
  - PhD thesis (2011)

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