WGNE intercomparison of Tropical Cyclone Track forecast, 2013

30th session of CAS/JSC WGNE,
23-26 Mar. 2015,
College Park, MD, U.S.A.

Prepared by
Yoichiro Ota, Takahiro Ito, Akira Shimokobe(NPD/JMA)
and Munehiko Yamaguchi (MRI/JMA)

STANDARD VERIFICATION

Verification of Global Models

History of the Project

- 1991 : commencement with three centers: ECMWF, UKMO and JMA. The verification area was only western North Pacific.
- 1994 : CMC joined.
- 1999 : Verification for the North Atlantic started.
- 2000 : DWD joined. Verification for the eastern North Pacific started.
- 2002 : Verification for 2 Southern Hemispheric regions, north Indian Ocean and the Central Pacific started.
- 2003 : NCEP and BoM joined. A website for this intercomparison project was launched.
- 2004 : Meteo-France and CMA joined.
- 2006 : CPTEC and NRL joined.
- 2011 : KMA joined. CMA came back.

2014: 10 NWP centers participated in the project.
〔BOM CMA CMC DWD ECMWF JMA France NCEP NRL UKMO 〕

Specification of Data

NWP centers	Participate Year	Bogus data / Relocation	Horizontal Res. of provided data	Model Res. as of 2013
BoM	2003	-	0.562x0.375	40kmL70
CMA	2004	used in WNP	1.25x1.25	T213L31
CMC	1994	-	1.0x1.0	33km L80 (~Feb 12) 25km L80 (Feb 13~)
DWD	2000	-	0.25x0.25	20kmL60
ECMWF	1991	-	0.125x0.125	T_L1279L91 (~Jun 24) T_L1279L137 (Jun 25~)
JMA	1991	used in WNP	0.25x0.25	T_L959L60
France	2004	used*1	0.5x0.5	T_L798C2.4L70
NCEP	2003	used in NH	1.0x1.0	T574 L64
NRL	2006	used	1.0x1.0 (~Mar 12) 0.5x0.5 (Mar 13~)	T319L42 (~Mar 12) T359L50 (Mar13~)
UKMO	1991	-	0.3515x0.2345	25kmL70

*1 except for South Pacific and north Indian-Ocean

Major upgrades of global NWP systems in this period

- CMC:
  - 2013.02.13 Increases horizontal resolution from 33km to 25km. Use of hybrid sigma-p vertical coordinate. Increase horizontal resolution of the inner model used in 4DVAR.
- ECMWF:
  - 2013.06.25 Increases the number of vertical layers from 91 to 137.
  - 2013.11.19 Enhanced 25 member EDA background error. Parameterization changes.
- Meteo France:
  - 2013.07.02 Assimilation of new satellite observations (ATMS and CriS on Suomi-NPP, OSCAT winds, Metop-B). Introduces wavelet approach for a flow-dependent B matrix from EDA. Parameterization changes.
- NCEP:
  - 2012.09.05 Bug-fix in land surface model.
- NRL:
  - 2013.03.13 Upgrades global NWP from NOGAPS (T319L42, Eulerian) to NAVGEM (T359L50, SL/SI)

Major upgrades after this period

- CMA:
  - 2014.07.11 Increases horizontal and vertical resolution from T213L31 to TL639L60.
- CMC:
  - 2014.11.18 Introduction of 4D-EnVar and IAU (Incremental Analysis Update). Increase number of ensemble members of EnKF from 192 to 256.
- DWD:
  - 2015.01.20 Replaces global model from GME to ICON. Horizontal resolution is increased from 20km to 13km.
- JMA:
  - 2014.03.18 Increases the number of vertical layers from 60 (top 0.1hPa) to 100 (top 0.01hPa). Parameterization changes. Use of AMSUA ch14 and ground-based GNSS. Assimilation of GNSSRO bending angle instead of refractivity.
  - 2014.09.04 Upgrades typhoon bogus. Assimilates hyperspectral IR sounders (AIRS and IASI).
- NCEP:
  - 2015.01.14 Increases horizontal resolution from T574 (Eulerian) to TL1534 (SL/SI). Parameterization changes.
- UKMO:
  - 2014.07.15 Increases horizontal resolution from 25km to 17km. Use of new dynamical core (ENDGame). Increases horizontal resolution of the analysis (from 60km to 40km).

Method of TC verification using MSLP

TCs to be verified

TCs which intensity reached tropical storm (TS) with the maximum sustained wind of 34 knots or stronger are set as targets for this verification. The tropical depression (TD) stage of the targeted TCs is also included in this verification. However, the TCs which stayed at TD level all through their life are excluded.

1. Tracking Method

local pressure minimum;

a) First position (FT +0hr) : search from the best track position
b) Second position (FT +6hr) : search from the first position
c) Third and after (FT +12hr~) : search from estimated position from the latest two positions

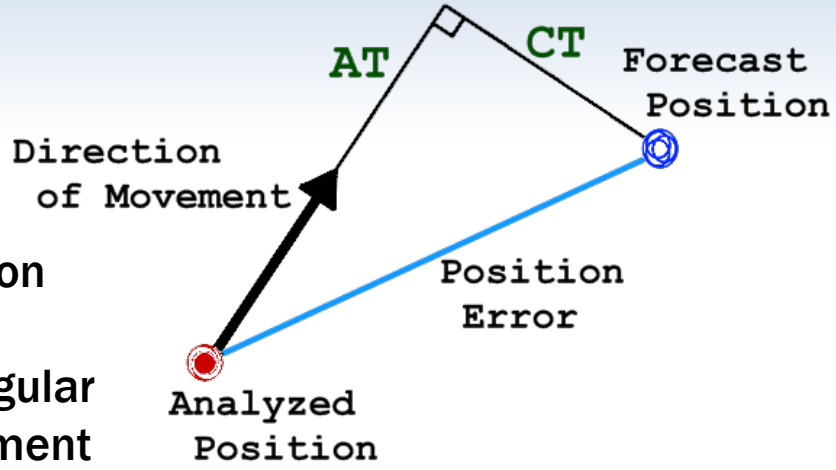
(all position searched within 500km radius)

Forecast time interval is changed from 12 hours to 6 hours for 2013 (in NH only).

2. Verification Method

- **Position Error〔km〕**

  The distance between
  the best-track (analyzed) position
  and the forecast position.



- **Along Track – Cross Track bias**

  AT(along-track)-bias : The bias in the direction of TC movement

  CT(cross-track)-bias : The bias in the rectangular direction of TC movement

- **Detection Rate**

  Detection Rate (t) = A(t)/ B(t)

A(t) : *The number of forecast events in which a TC is analyzed at forecast time t on the condition that a NWP model continuously expresses the TC until the forecast time t.*

B(t) : *The number of forecast events in which a TC is analyzed at forecast time t.*

Note that following verification results are using inhomogeneous samples otherwise noticed
The verification method for TC detection rate may be in favor of the NWP system that generates more TCs than actual, because the false alarm is not considered in the metric.

TC Verification

TC tracks on 2013 season

Northern-Hemisphere [2013/01/01 to 2013/12/31]

Southern-Hemisphere [2012/09/01 to 2013/08/31]

Number of TCs , [best-track data provider]

31 western North-Pacific [RSMC Tokyo]

20 eastern North-Pacific (including Central-Pacific) [RSMC Miami, Honolulu]

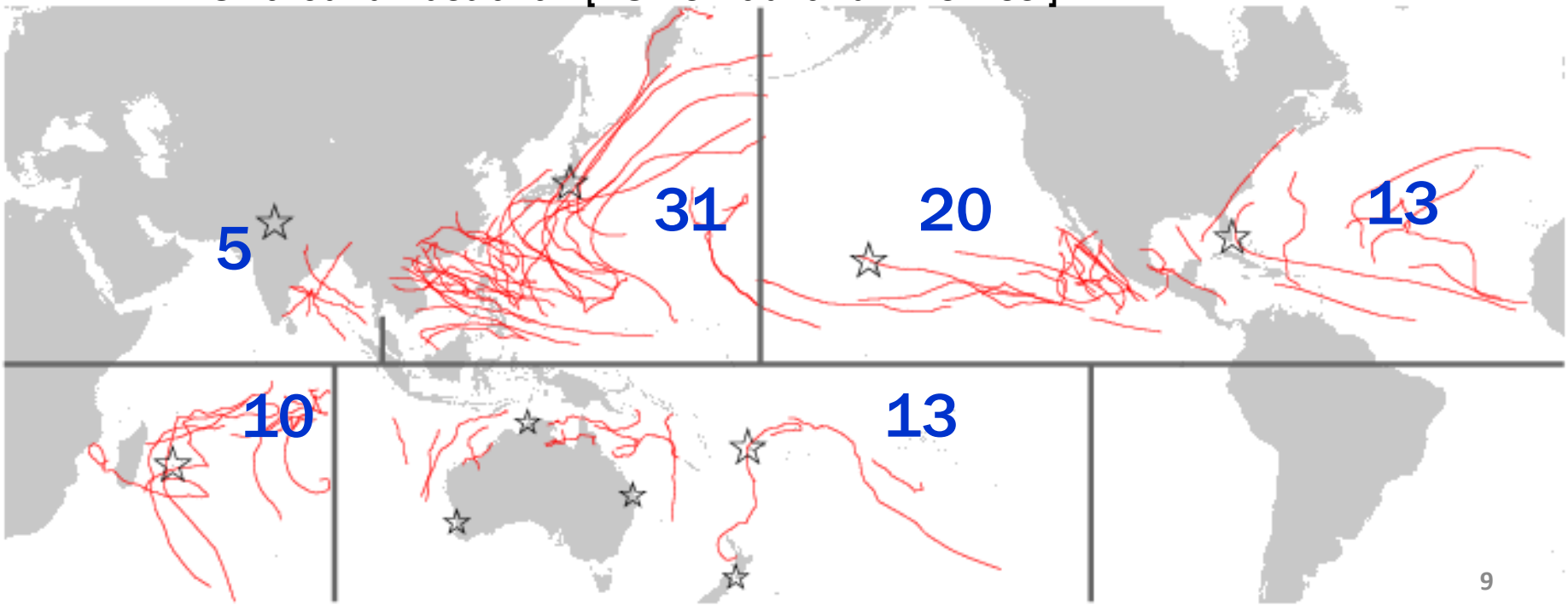
13 North Atlantic [RSMC Miami]

5 north Indian-Ocean [RSMC New-Delhi]

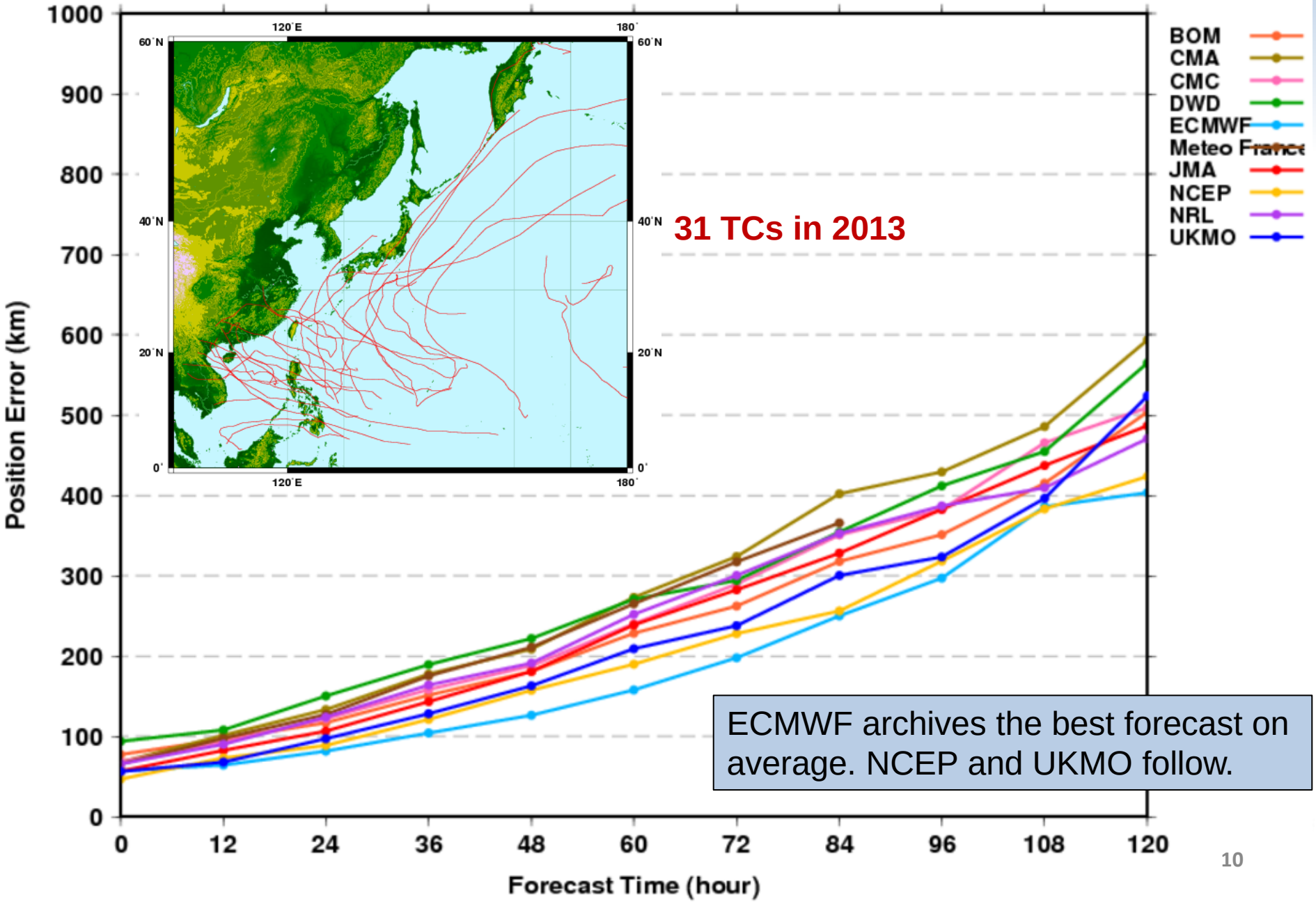
10 south Indian-Ocean [RSMC La-Reunion]

13 around Australia [RSMC Nadi and 4 TCWCs]

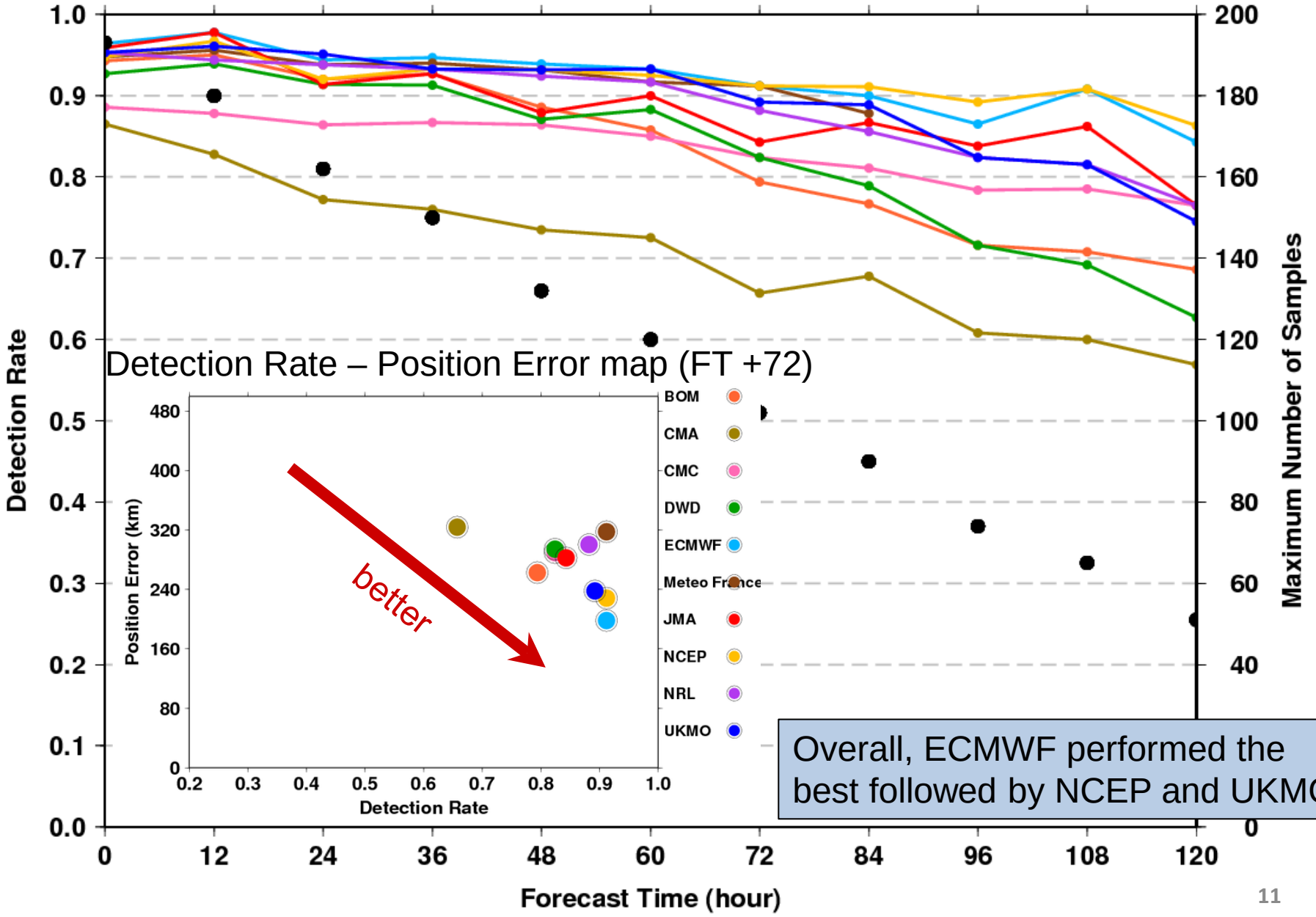
Include “operational” track data (for 8 TCs)



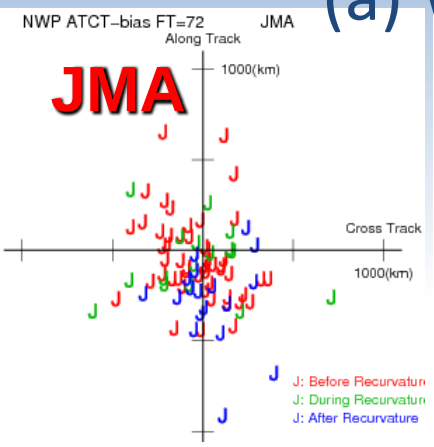
(a) western North-Pacific (WNP) domain Position Error

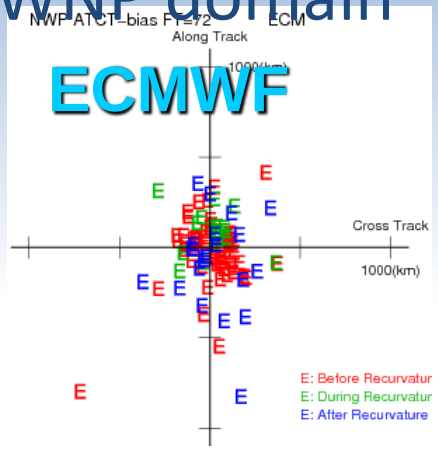


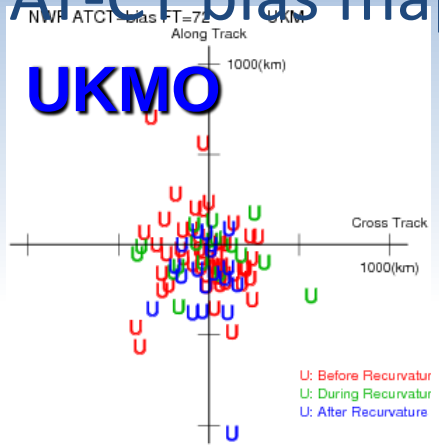
(a) WNP domain Detection Rate

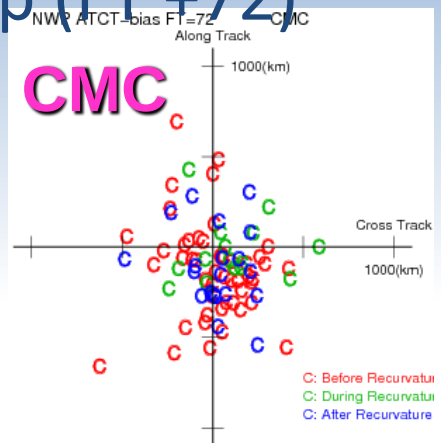


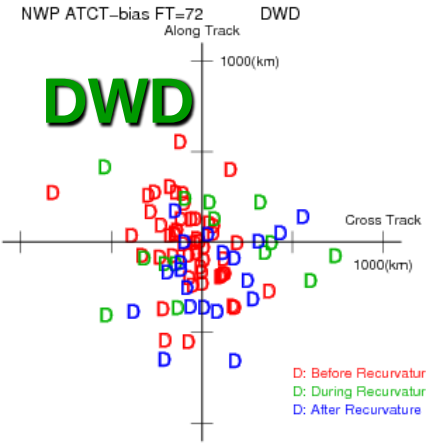
(a) WNP domain AT-CT bias map (FT +72)

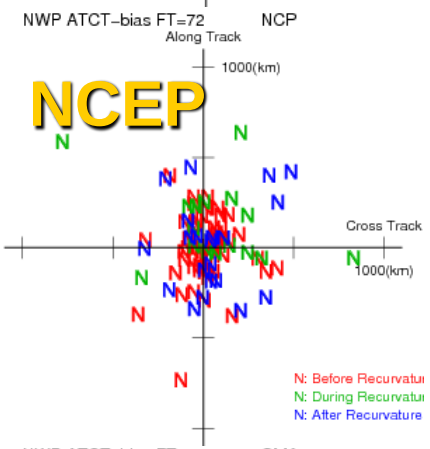


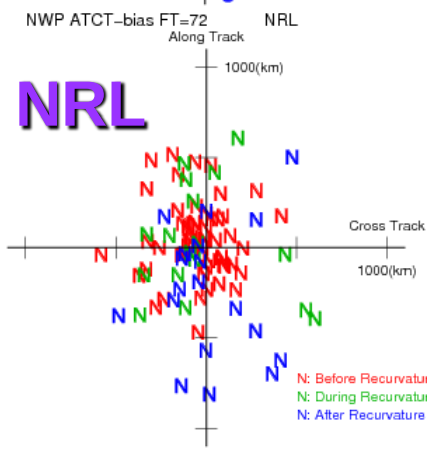


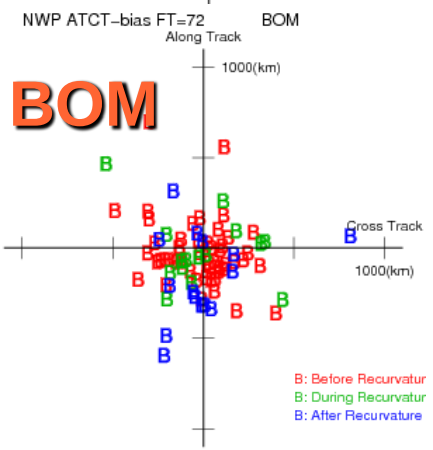


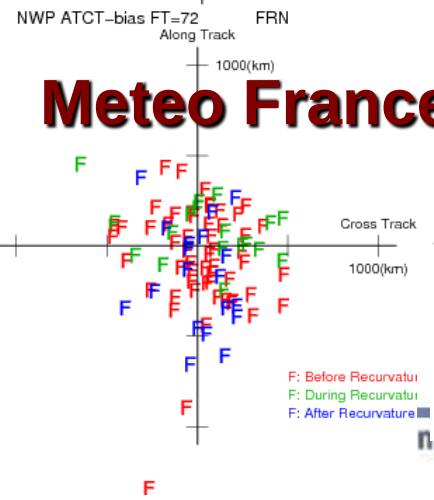


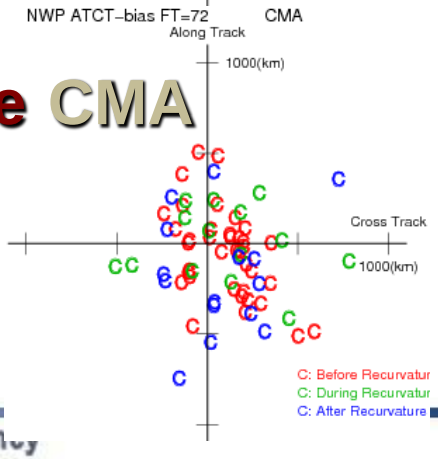












Scatter diagram of TC positions at 72 hour forecast.

Red : Before recurvature

Green : During recurvature

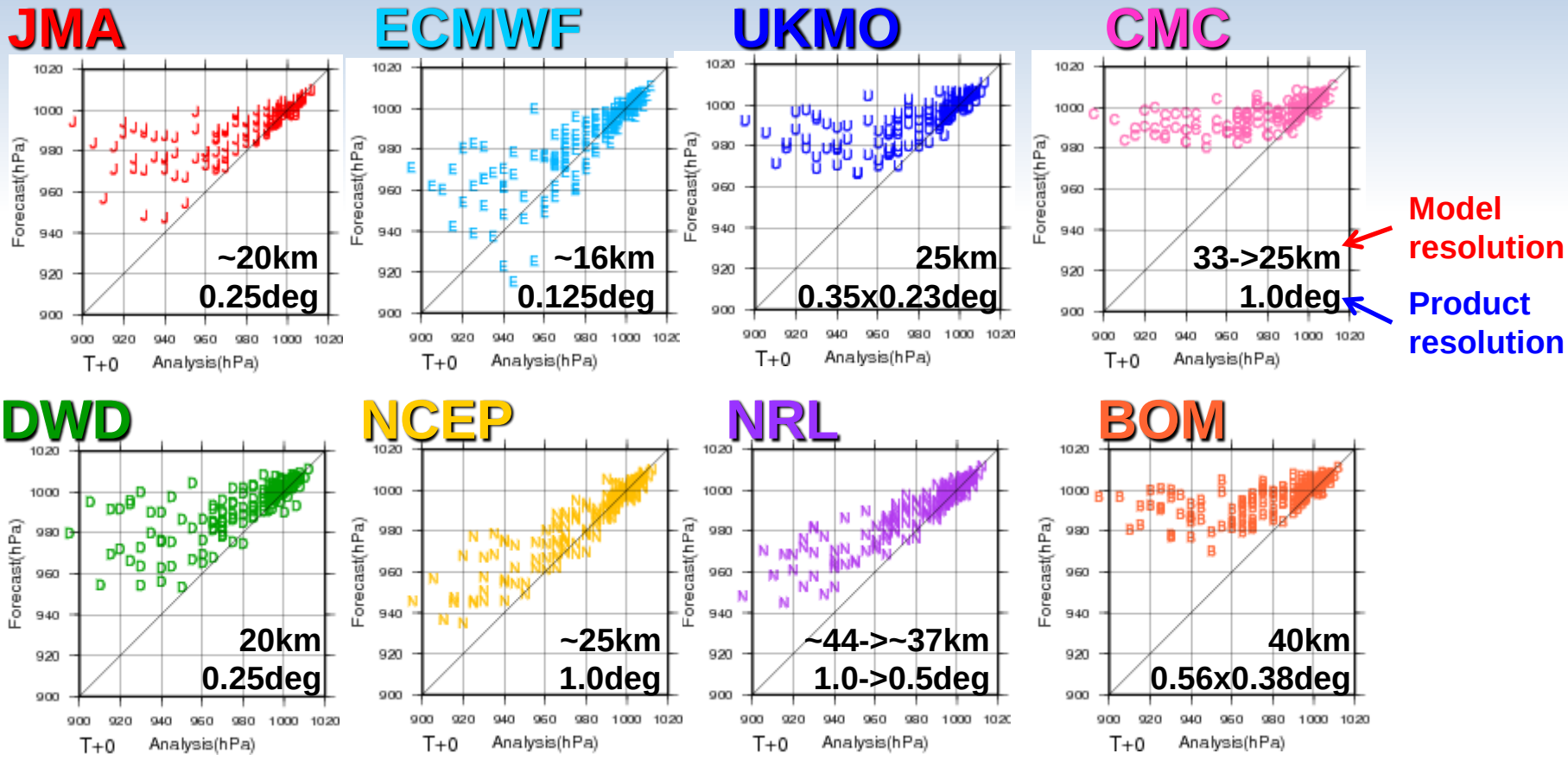
Blue : After recurvature

Y-axis represents position errors in Along Track (AT) direction and X-axis does that in Cross Track (CT) direction.

Unit: km

There is a significant slow bias after recurvature for JMA, UKMO, DWD and NRL.

(a) WNP domain Central Pressure scatter diagram (FT +0)



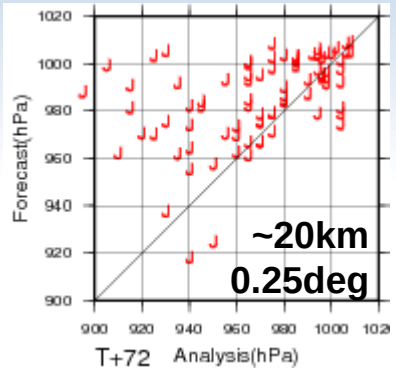
Scatter diagram of central pressure at initial.

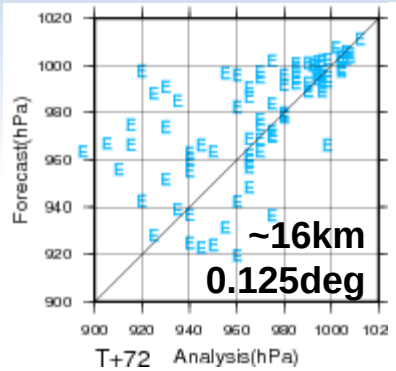
Y-axis represents central pressure of forecast and X-axis does that of analysis.

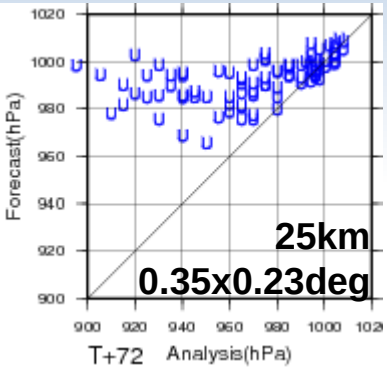
Unit: hPa

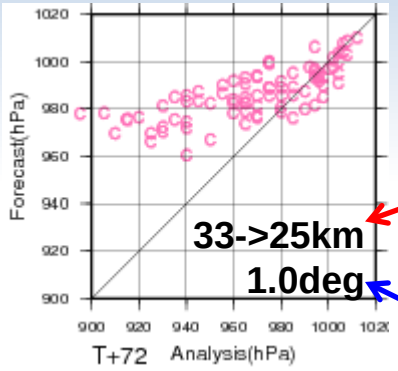
Nice linear relationship can be found for NCEP and NRL at the initial time.

(a) WNP domain Central Pressure scatter diagram (FT +72)



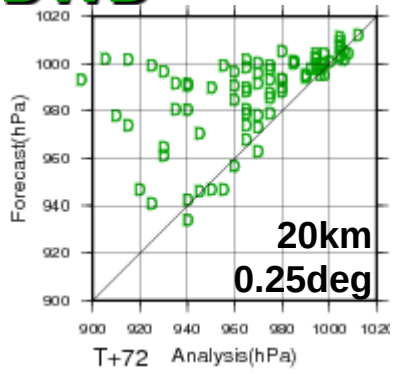


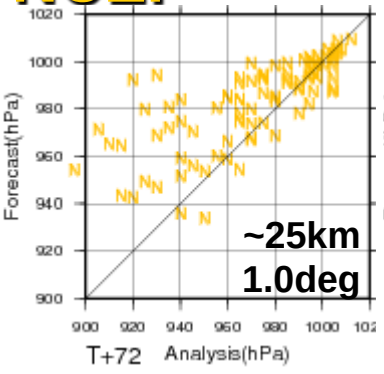


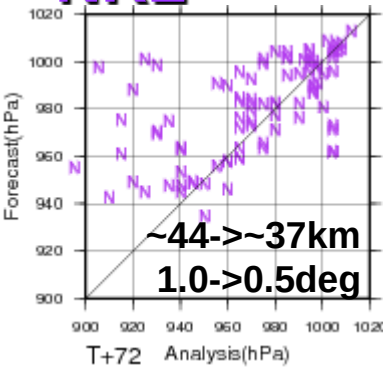


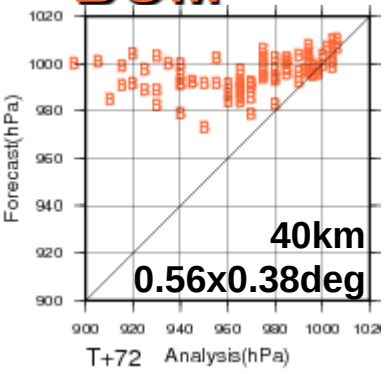
Model resolution

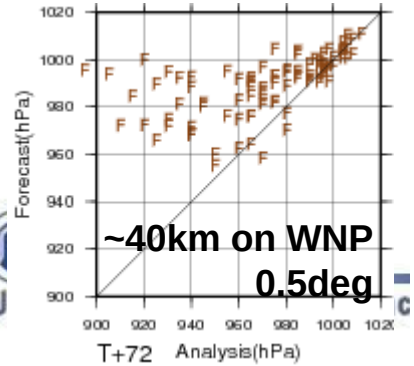
Product resolution

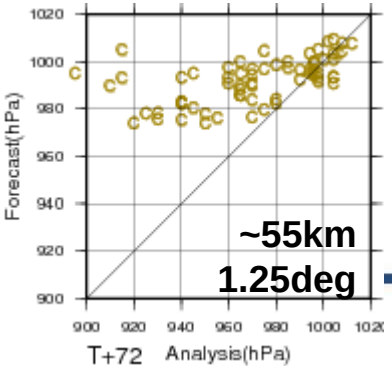












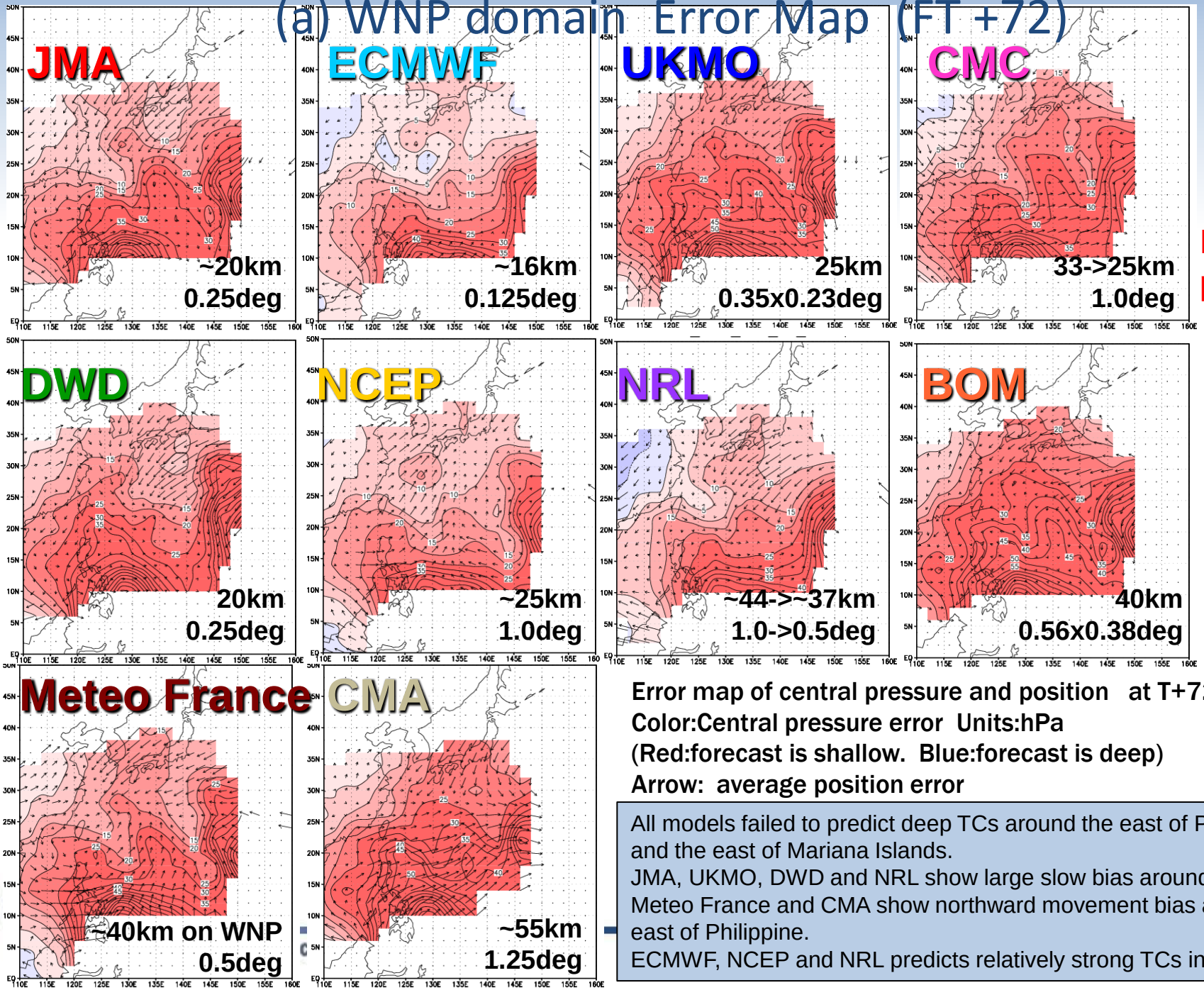
Same as previous slide but for T+72 hour

UKMO, CMC, BOM and CMA predict relatively shallow TCs compared to the best track.

Note; the results depend on the horizontal resolution of the NWP model and gridded data

TCs represented in CMC and Meteo France model tend to get stronger from initial time to T+72 hour, while those in UKMO model tend to get weaker

(a) WNP domain Error Map (FT +72)



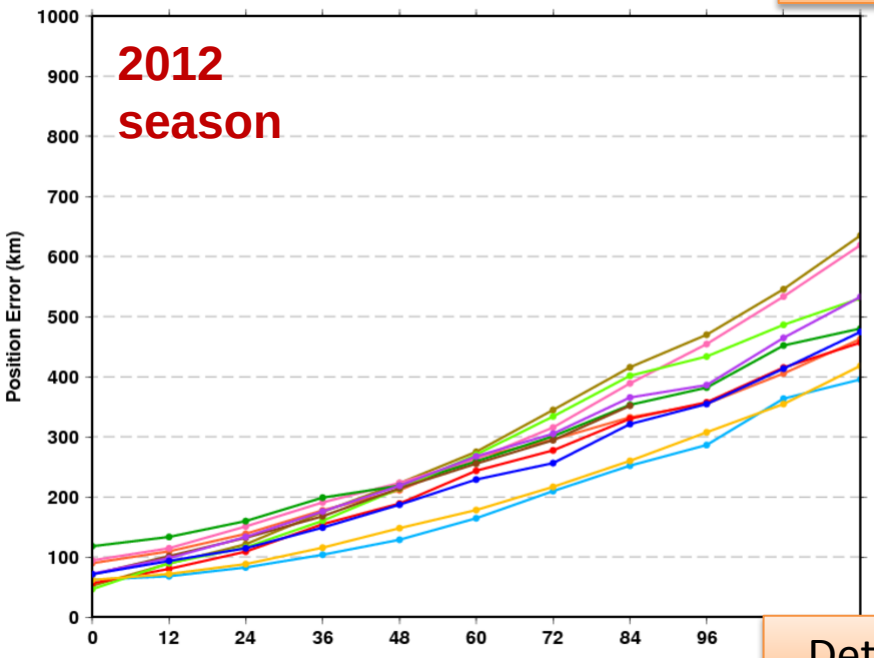
Forecast position

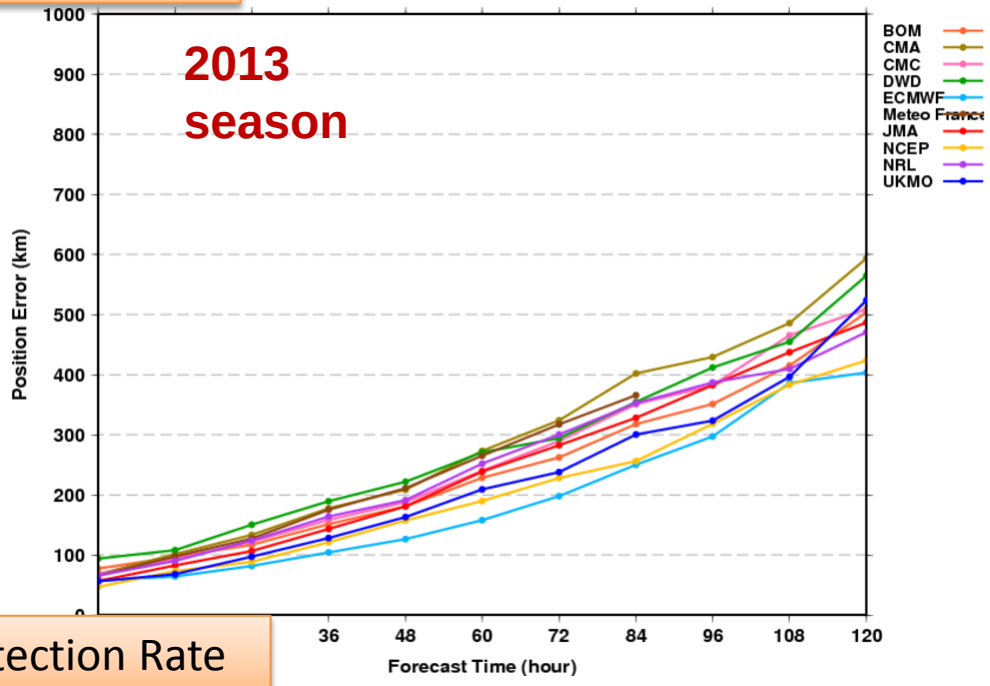
Analysis position

Error map of central pressure and position at T+72 hour
Color:Central pressure error Units:hPa
(Red:forecast is shallow. Blue:forecast is deep)
Arrow: average position error

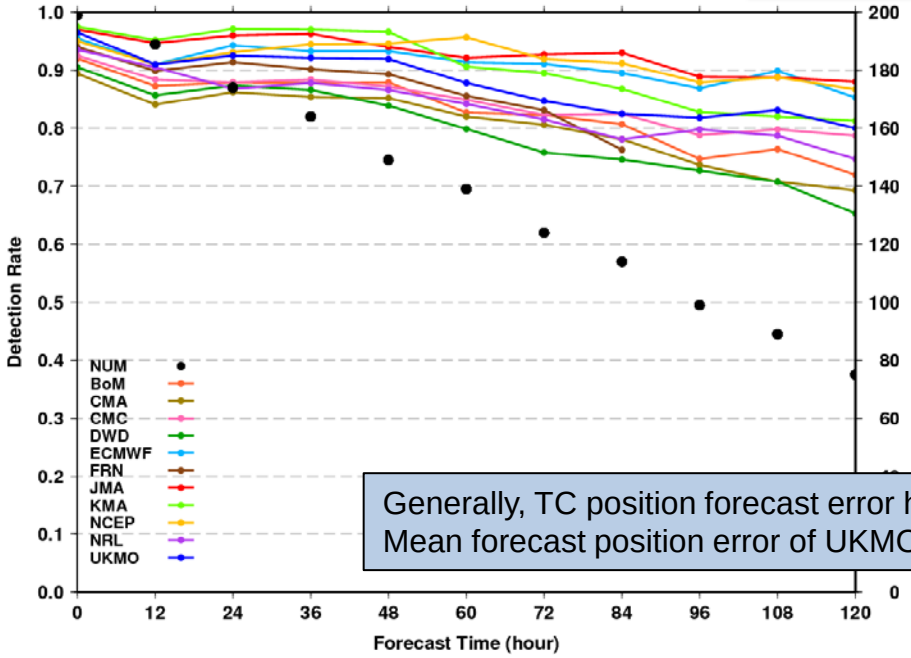
All models failed to predict deep TCs around the east of Philippine and the east of Mariana Islands.
JMA, UKMO, DWD and NRL show large slow bias around Japan.
Meteo France and CMA show northward movement bias around the east of Philippine.
ECMWF, NCEP and NRL predicts relatively strong TCs in mid-latitude

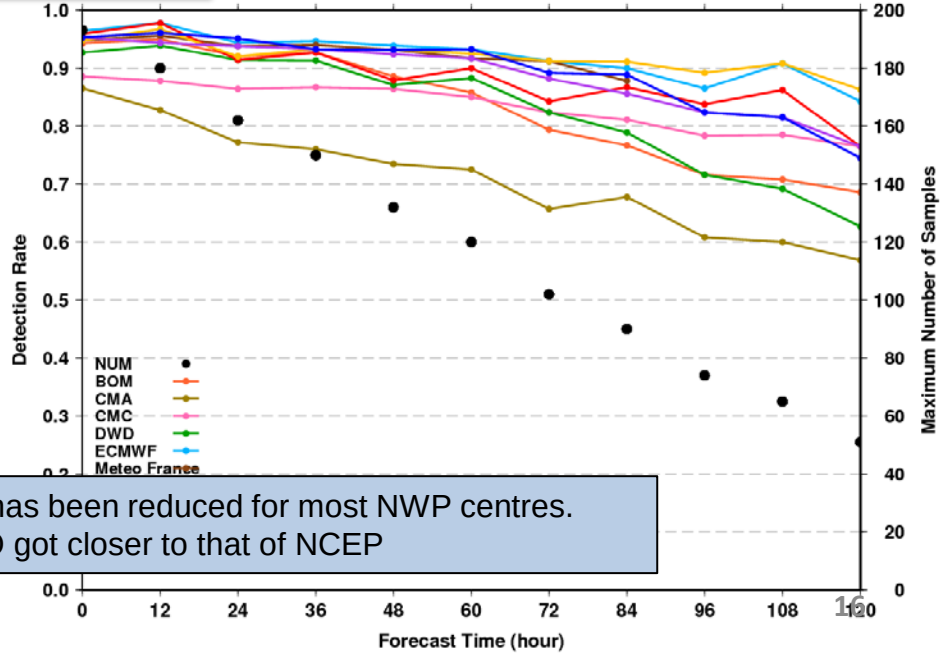
Position Error





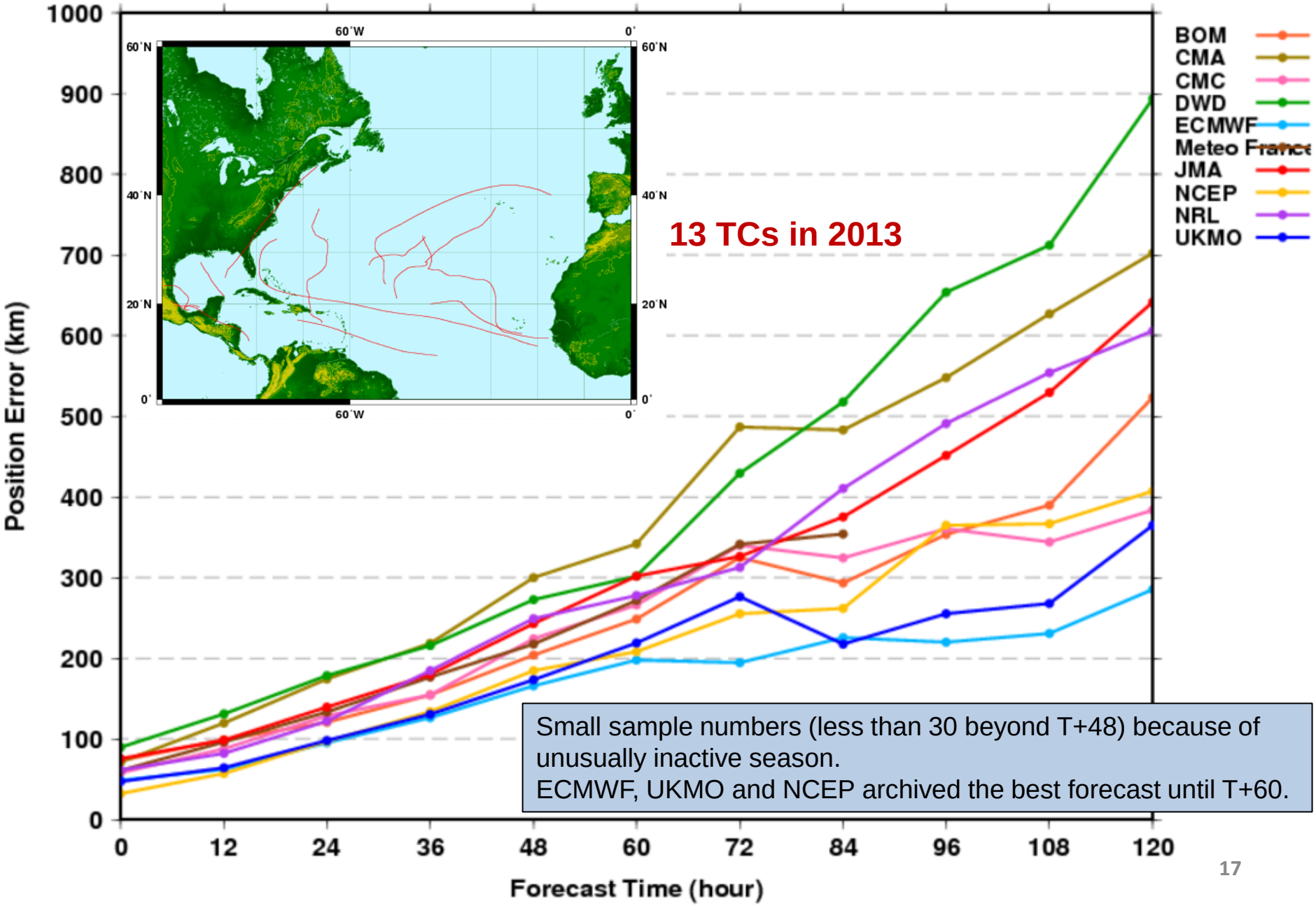
Detection Rate



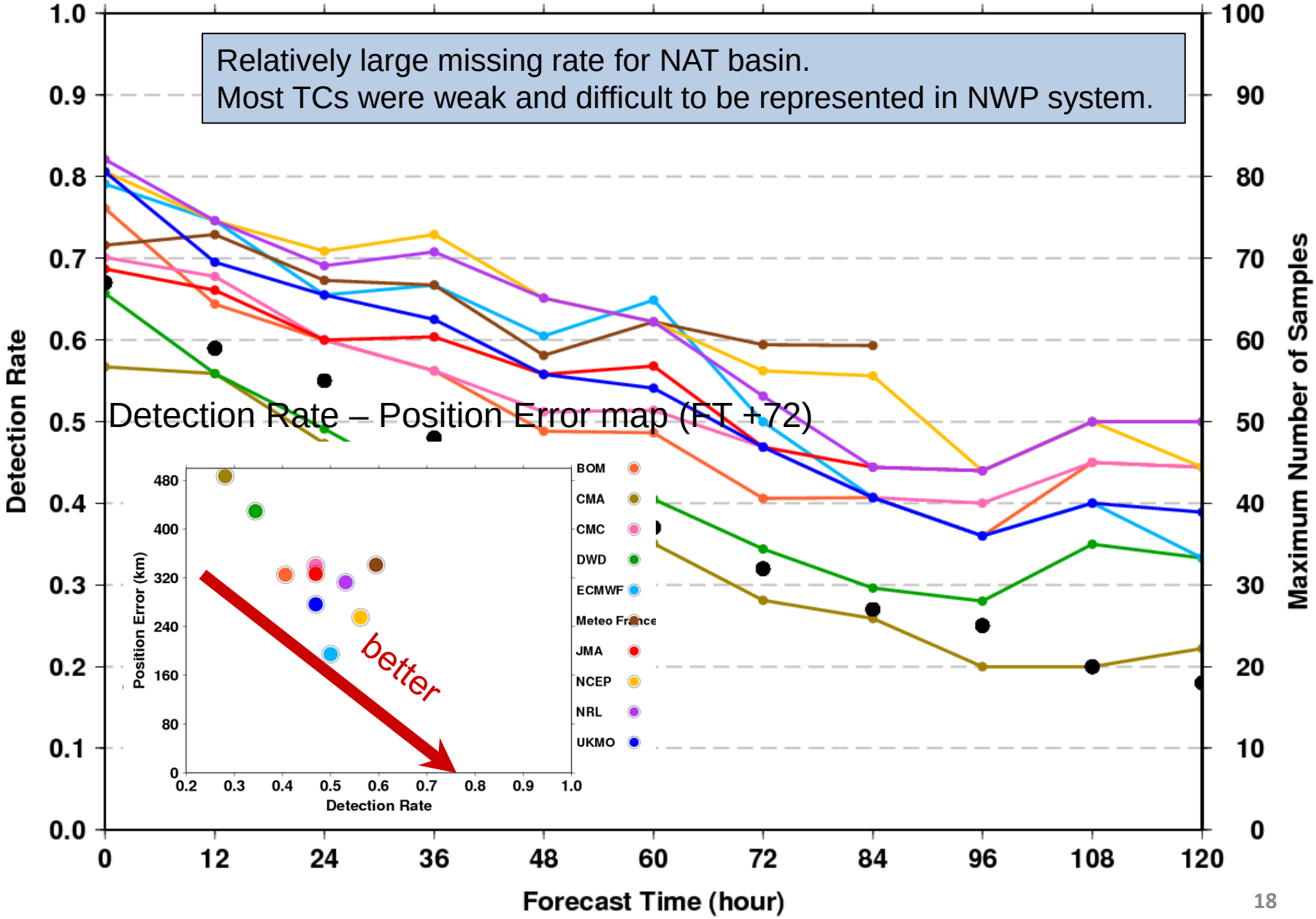


Generally, TC position forecast error has been reduced for most NWP centres.
Mean forecast position error of UKMO got closer to that of NCEP

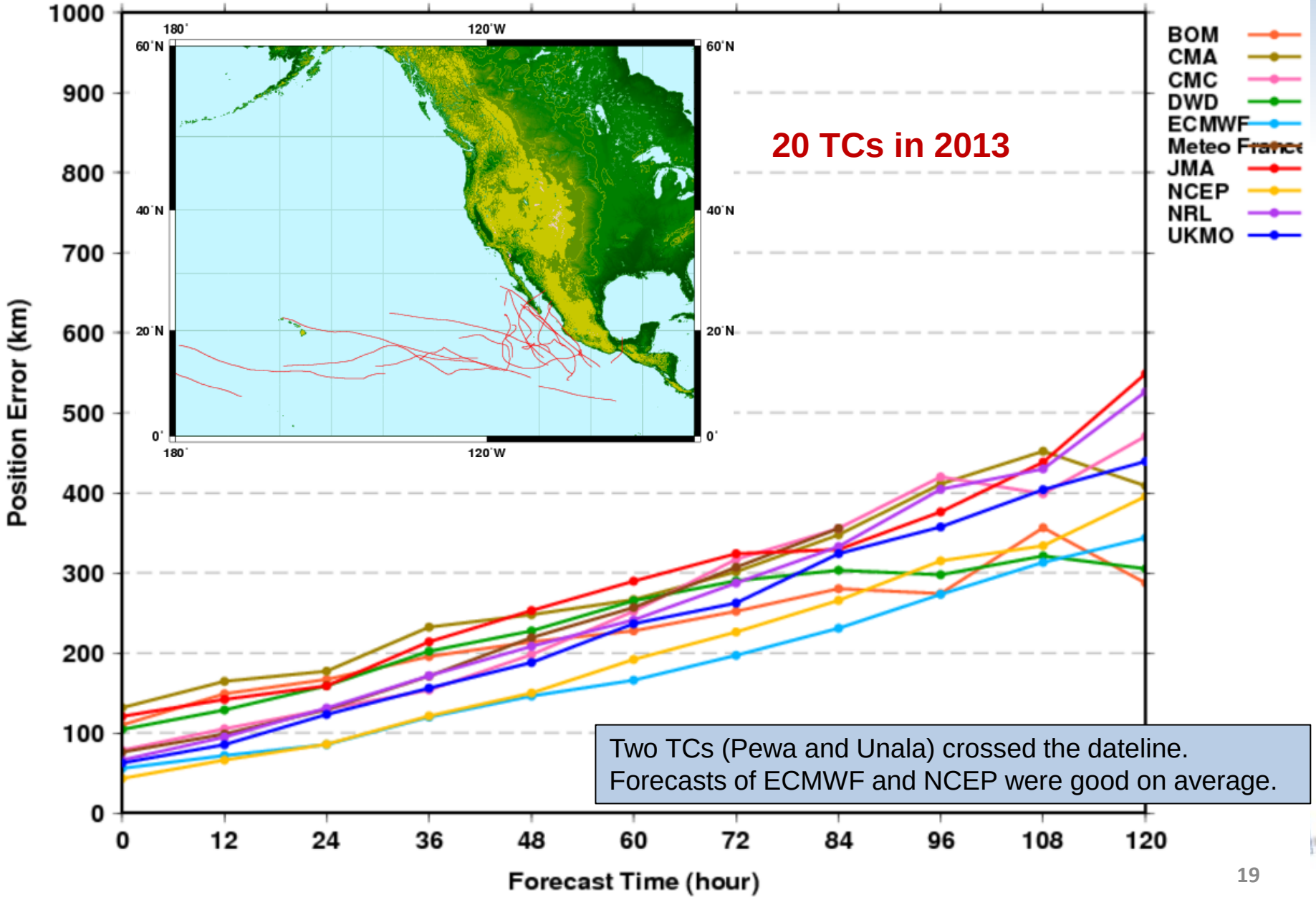
(b) North-Atlantic (NAT) domain Position Error



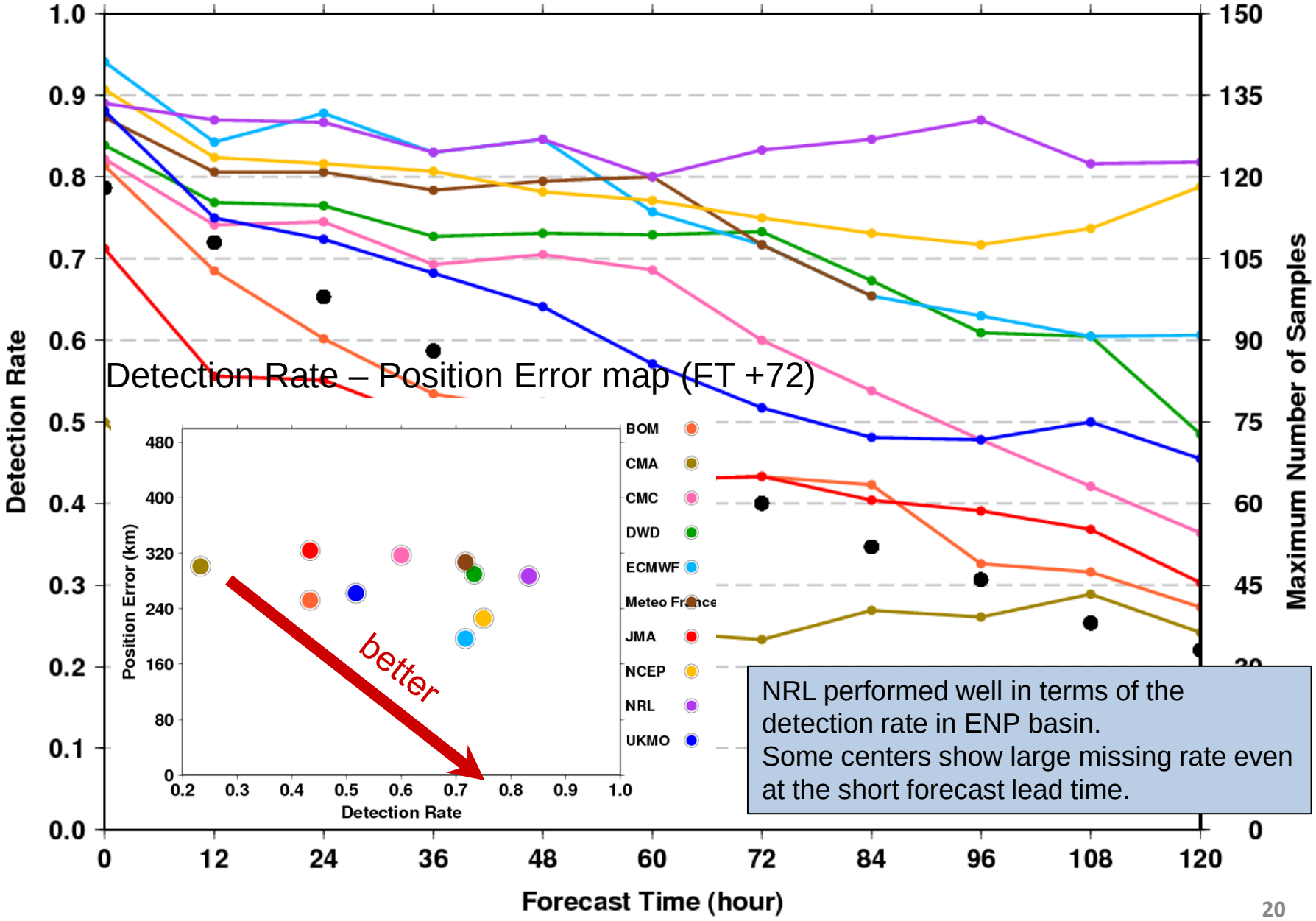
(b) NAT domain Detection Rate



(c) eastern North-Pacific (ENP) domain Position Error

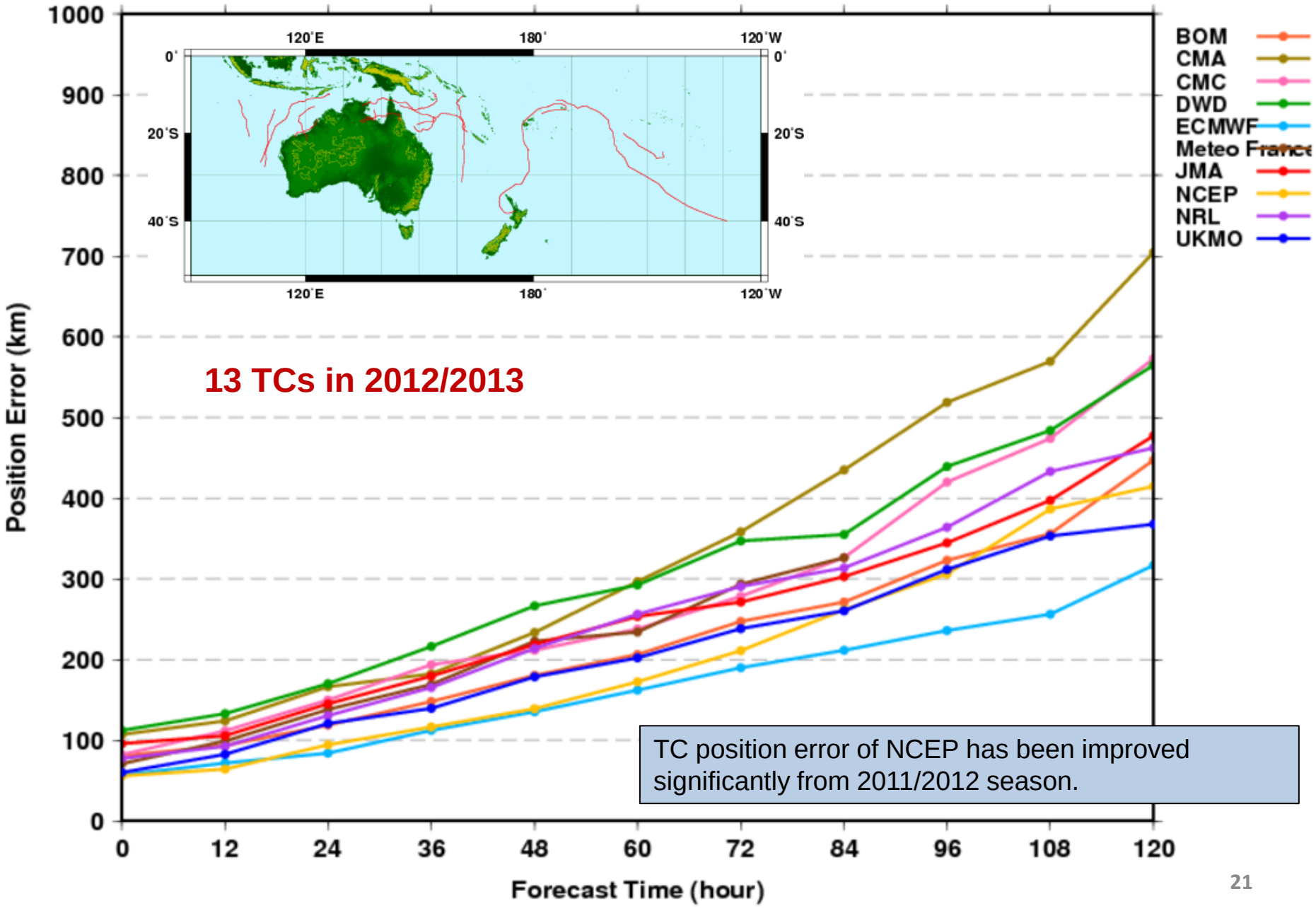


(c) ENP domain Detection Rate

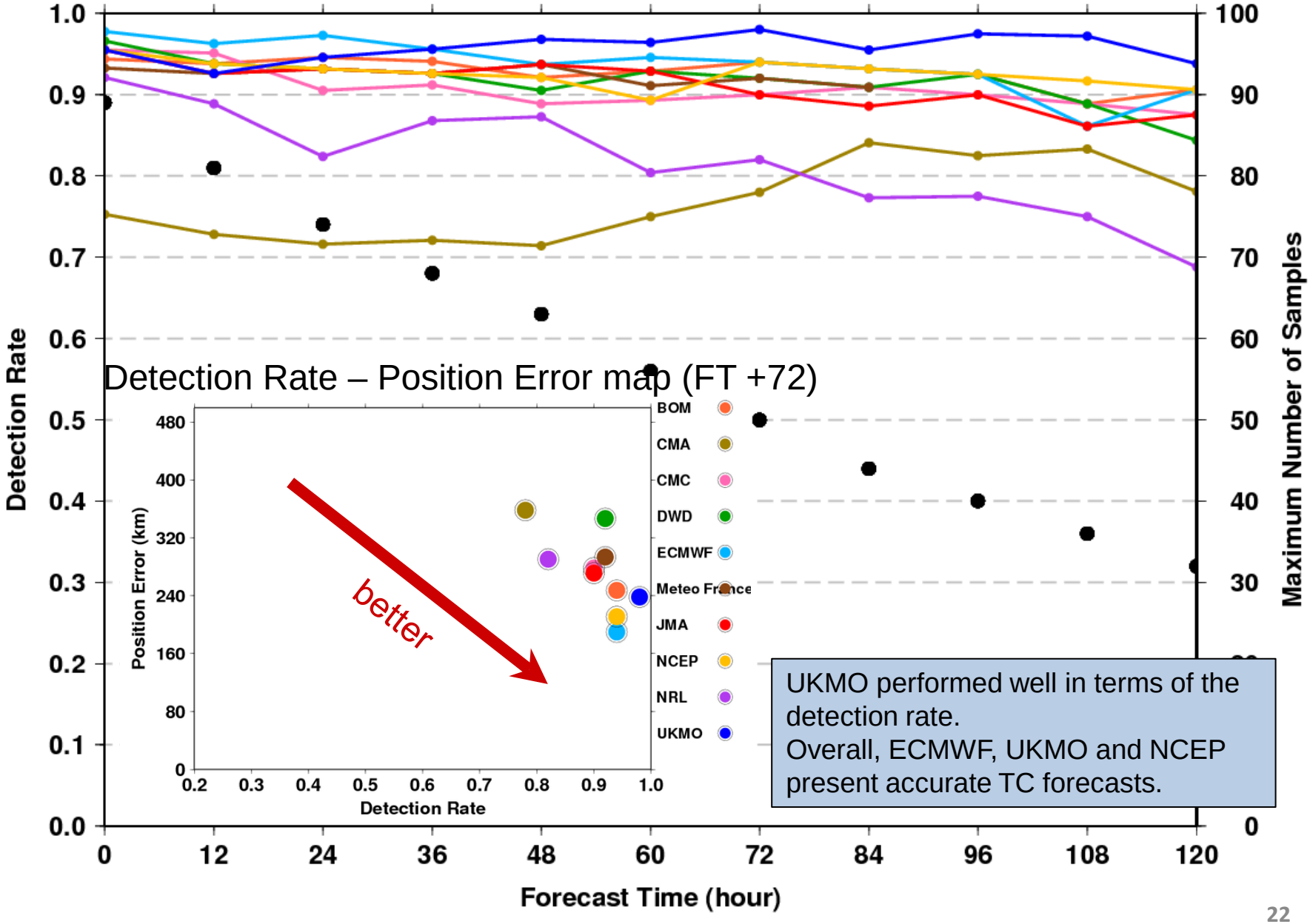


NRL performed well in terms of the detection rate in ENP basin.
Some centers show large missing rate even at the short forecast lead time.

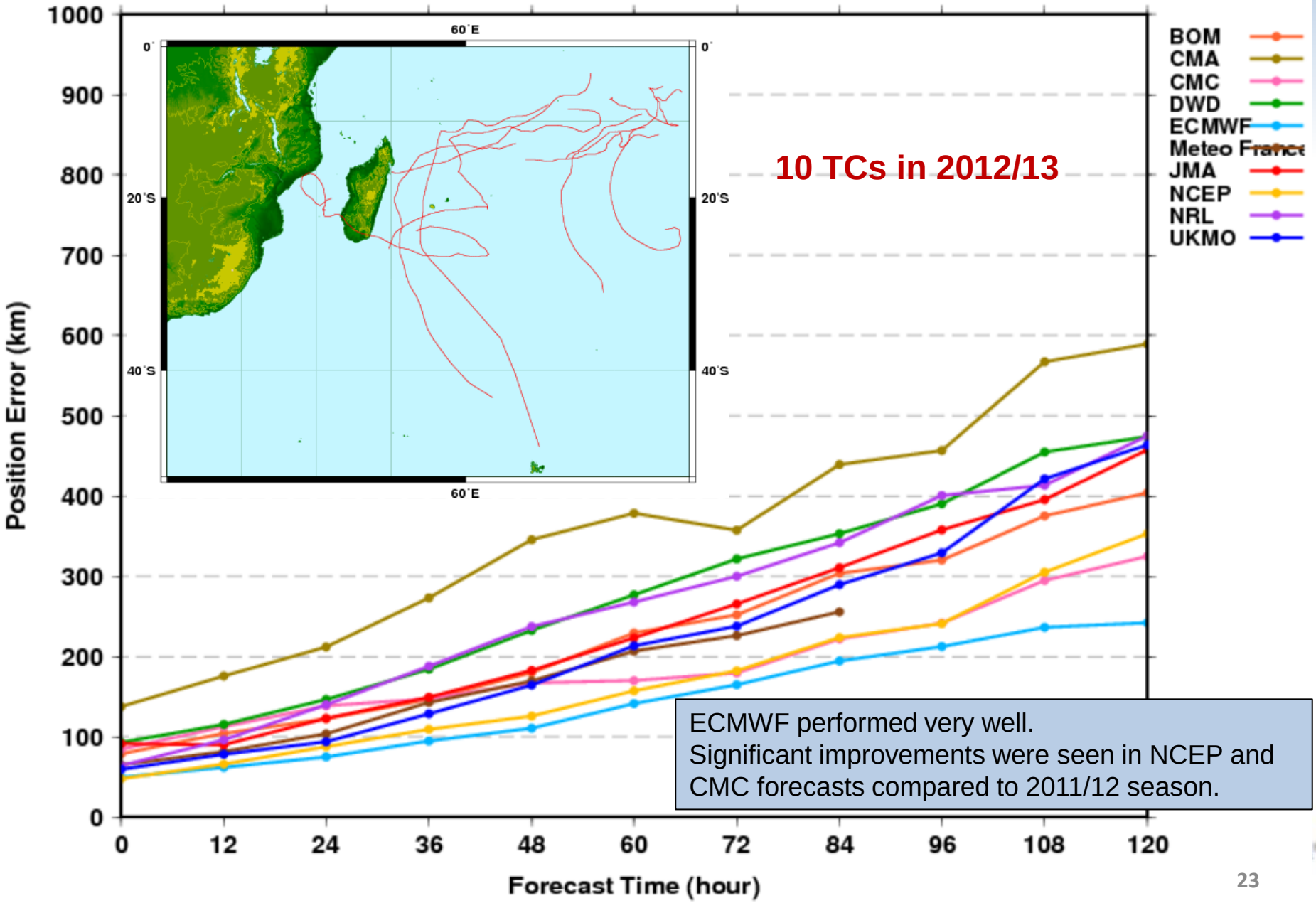
(d) “around Australia” (AUR) domain Position Error



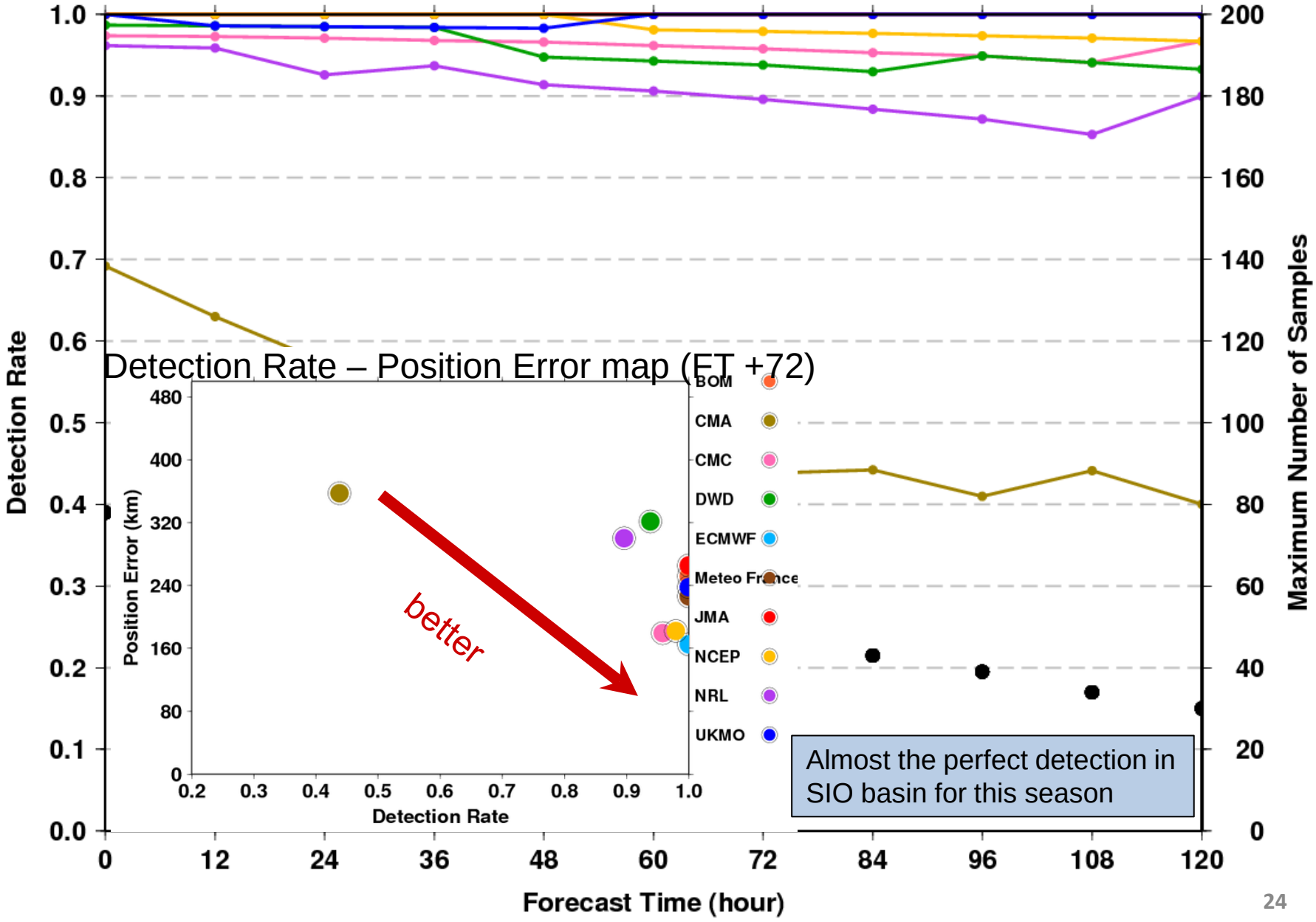
(d) AUR domain Detection Rate



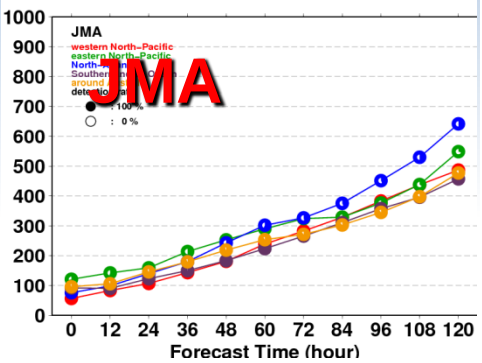
(e) South Indian Ocean (SIO) domain Position Error

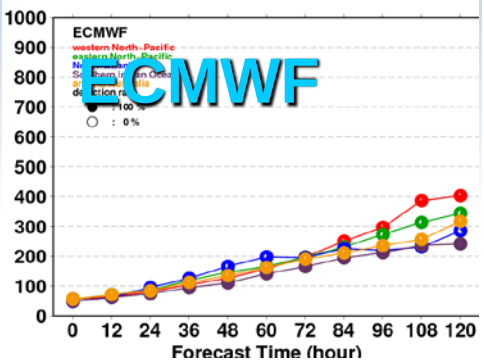


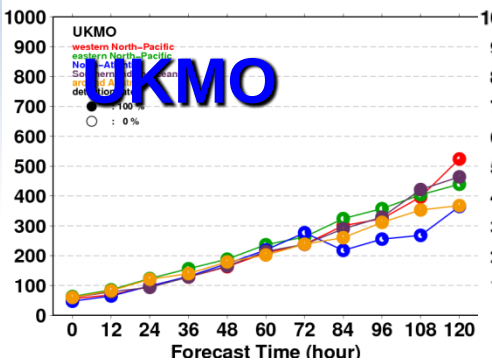
(e) SIO domain Detection Rate

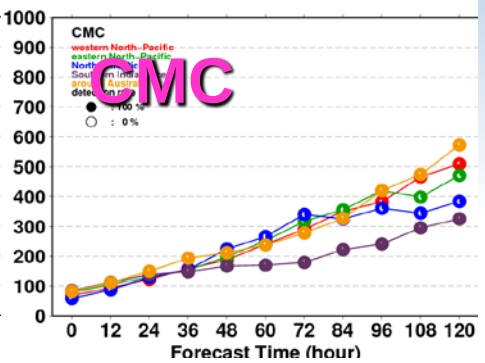


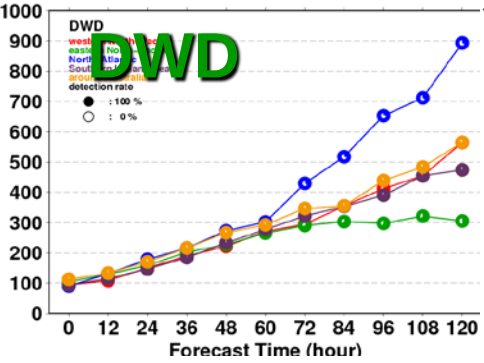
visualization with “pie-chart”

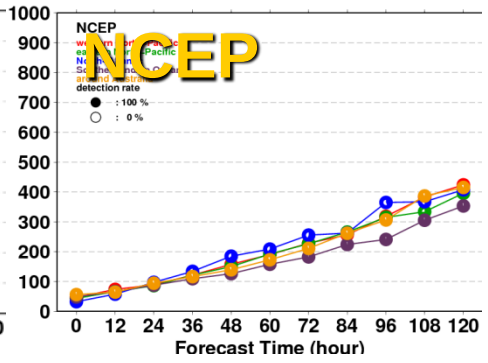


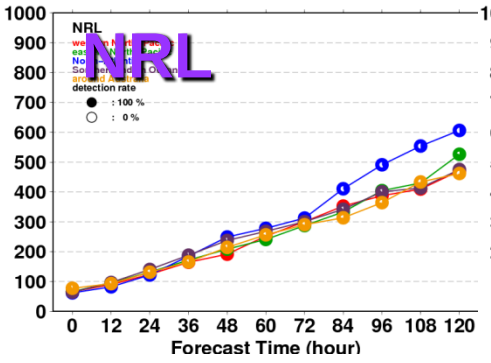


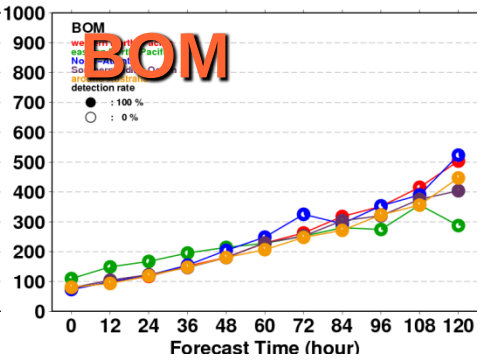


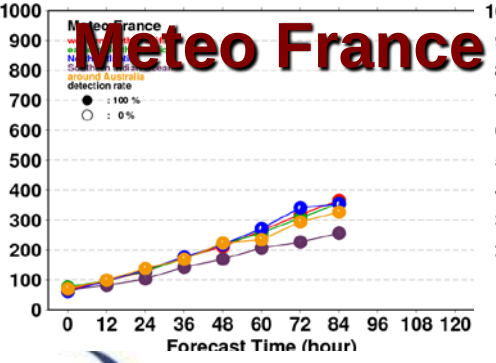


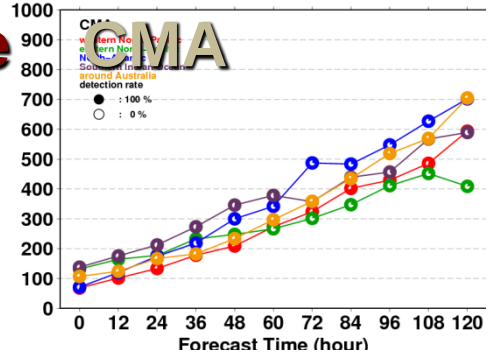












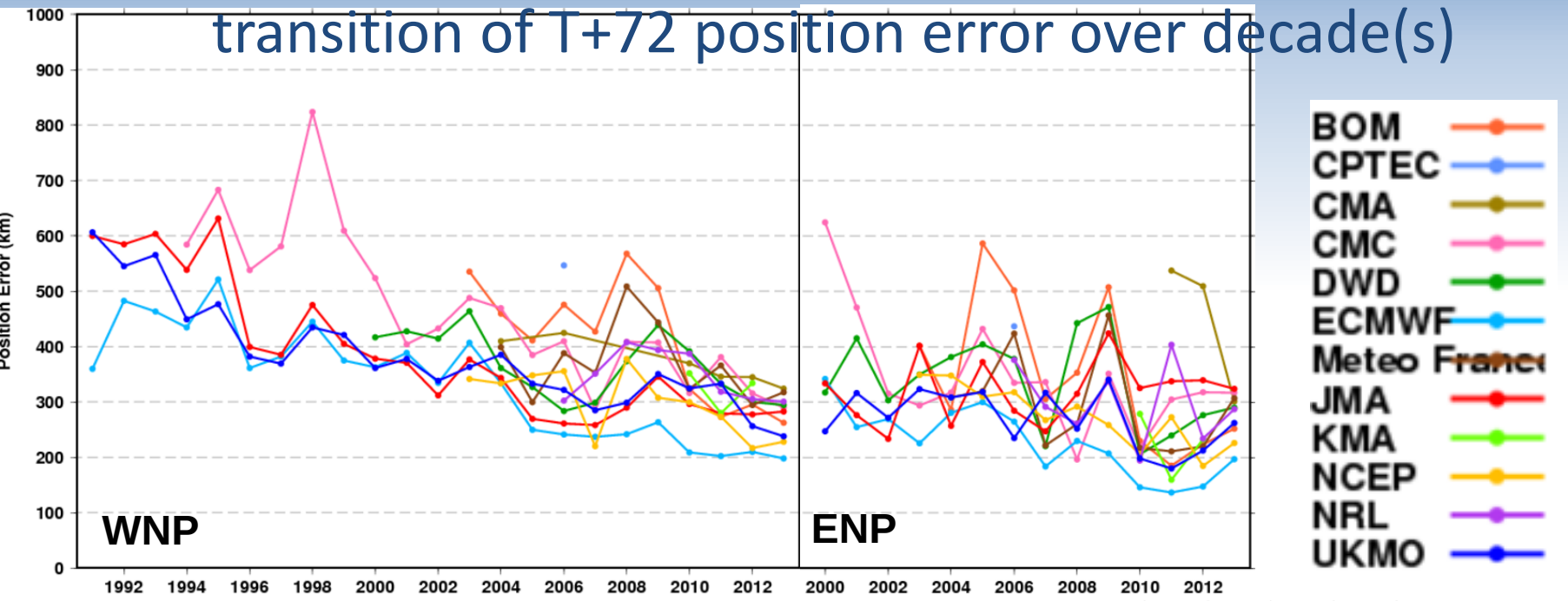
Western North-Pacific
Eastern North-Pacific
North-Atlantic
Around Australia
Southern Indian Ocean

Detection rate: ●, 100%, ○, 0%

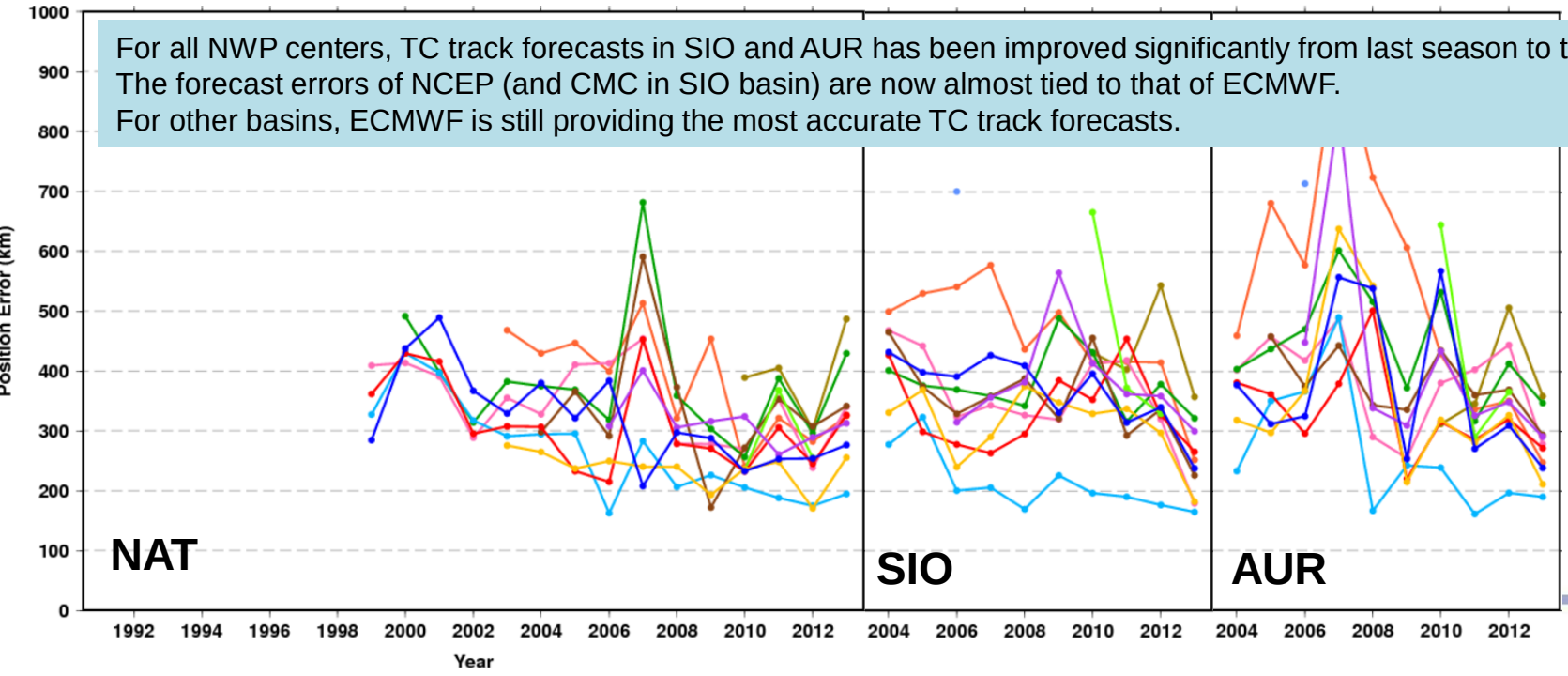
NCEP, CMC and Meteo France is relatively good at TC track forecasts in SIO domain.
TC track forecasts of JMA, DWD and NRL in North Atlantic are not as accurate as those in other basins.
ECMWF and NCEP provide the accurate TC track forecasts over the all basins.

気象庁
Japan Meteorological Agency

transition of T+72 position error over decade(s)



For all NWP centers, TC track forecasts in SIO and AUR has been improved significantly from last season to this season
The forecast errors of NCEP (and CMC in SIO basin) are now almost tied to that of ECMWF.
For other basins, ECMWF is still providing the most accurate TC track forecasts.



TC intercomparison website is available now!

WGNE Intercomparison of Tropical Cyclone Track Forecasts Using Operational Global Models

Updated : 24 Mar 20

Forecast | Verification | Verification-Regional | Intro | Readme | DataSpec | DataSpec(regional) | Contact | Link

Verification Result

please select the region on the map; the verifications will pop-up.

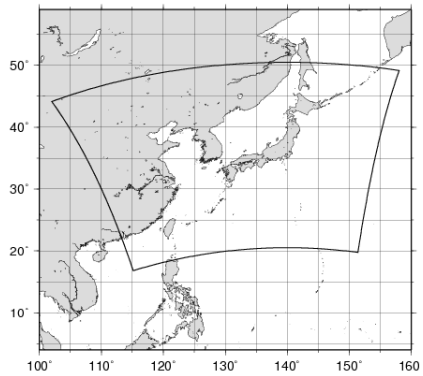
<http://nwp-verif.kishou.go.jp/wgne_tc/index.html>
Login ID: verif
Password: wgne2014 (beyond 20 Mar. 2015)
Contact: wgne_tc@naps.kishou.go.jp

ADDITIONAL VERIFICATION

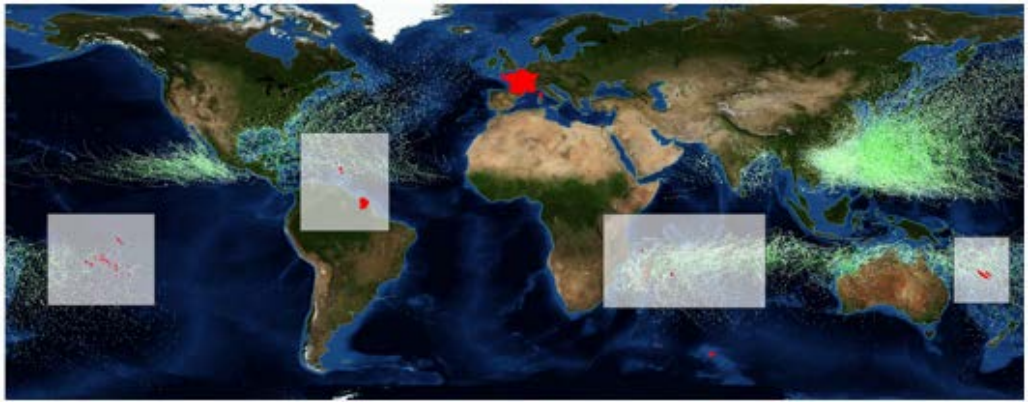
Verification of Regional Models

Specification of Regional Models

NWP centers	Name of Model	Verification Region	Boundary	Bogus data	Model Res. as of 2013
JMA	MSM	WNP*	GSM	Used	5kmL50
Meteo France	ALADIN	AUR NAT ** SIO	IFS(AUR,NAT) ARPEGE(SIO)	Used	8kmL70
NCEP	HWRF	NAT,ENP	GFS	Used	3/9/27kmL42 (triple nest)



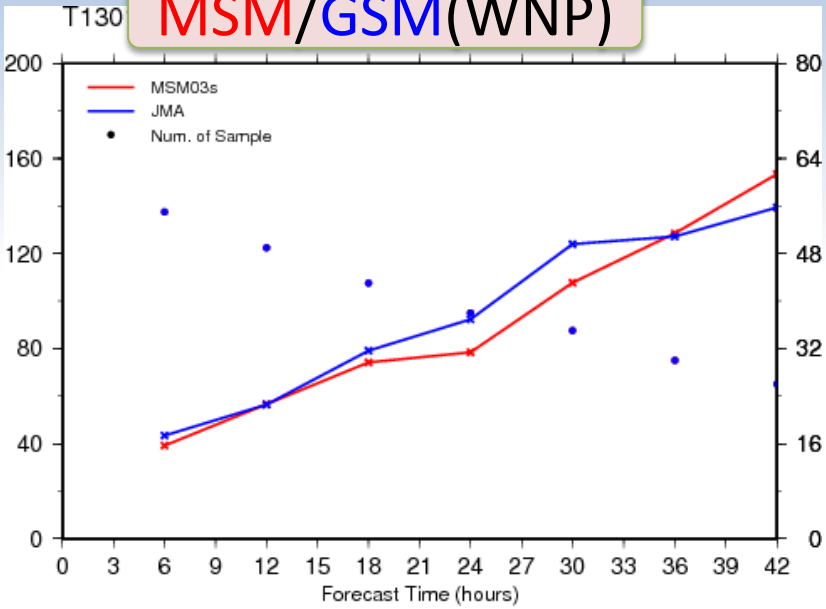
*Region of MSM



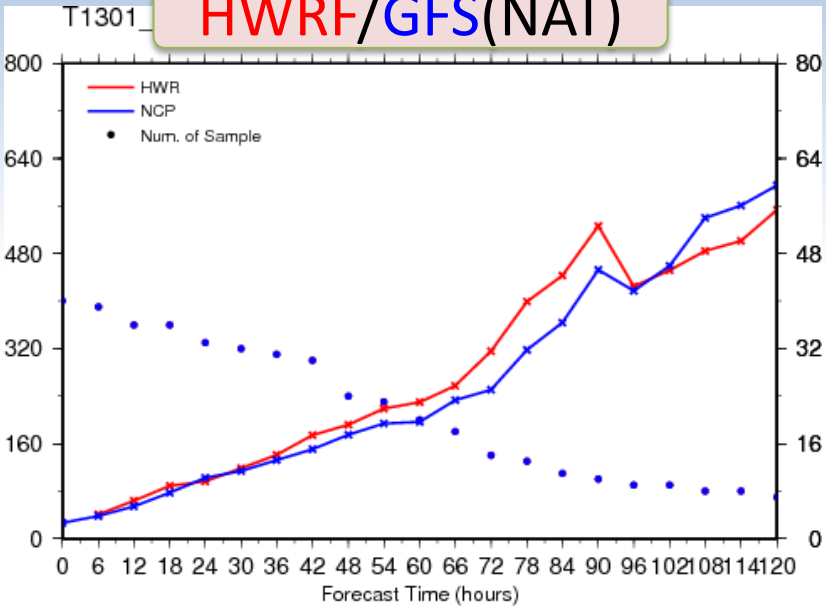
** Region of ALADIN

Position Error of homogeneous samples

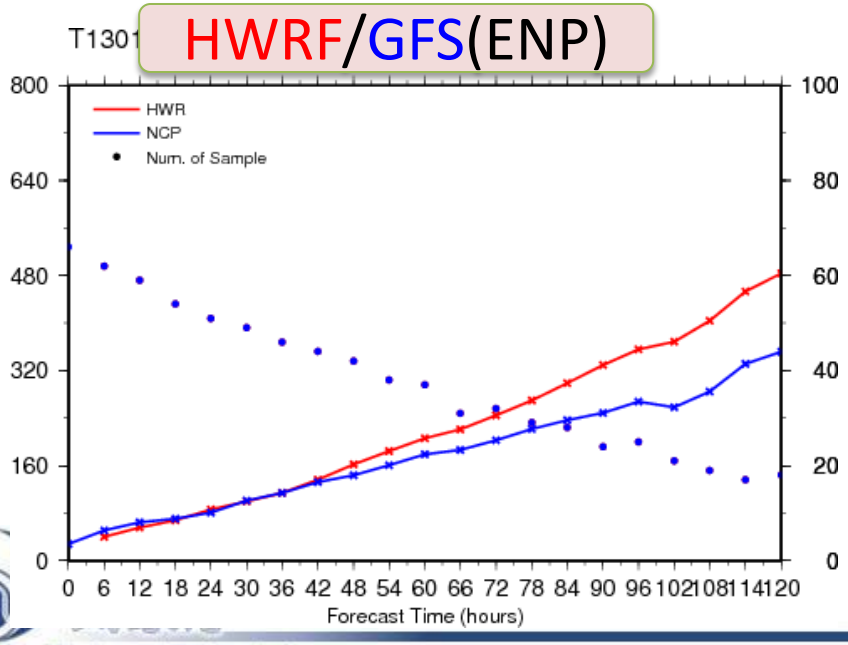
MSM/GSM(WNP)



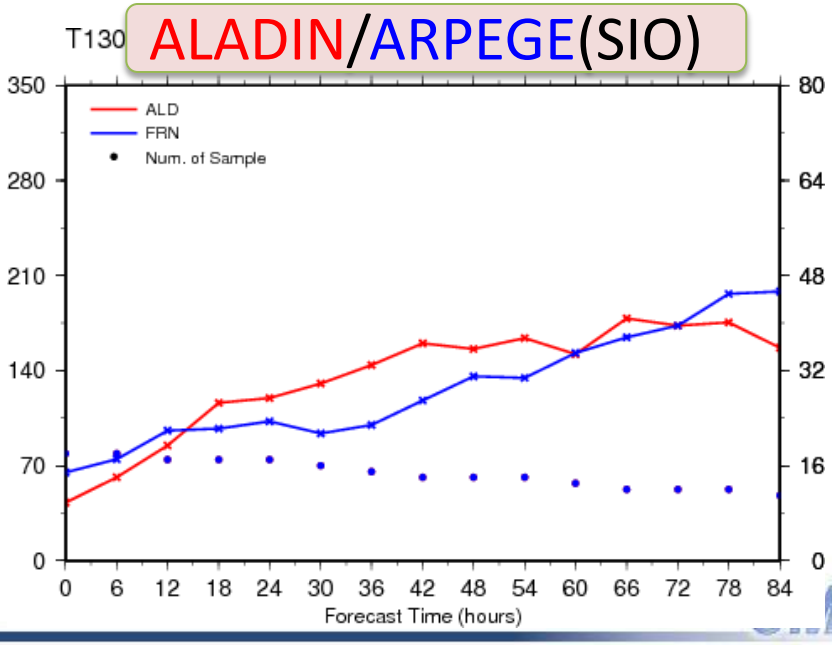
HWRF/GFS(NAT)



HWRF/GFS(ENP)

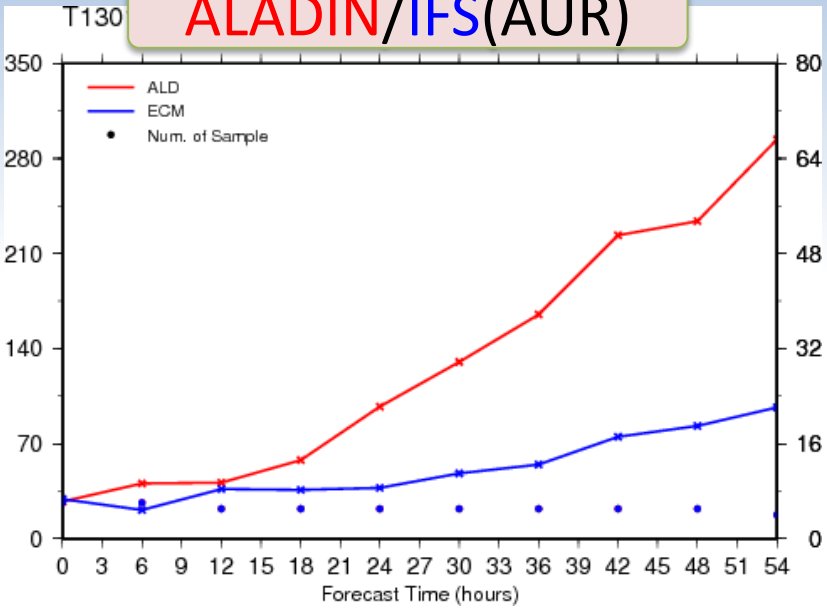


ALADIN/ARPEGE(SIO)

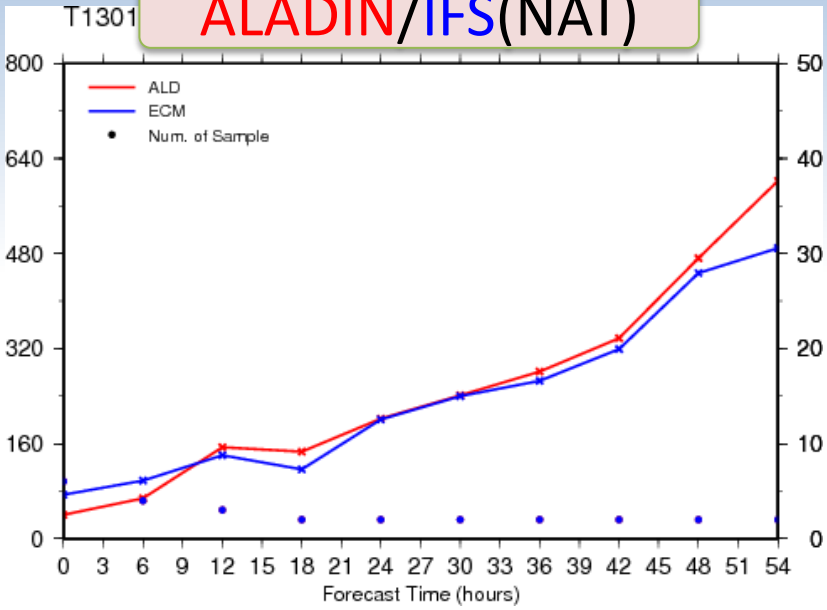


Position Error of homogeneous samples

ALADIN/IFS(AUR)



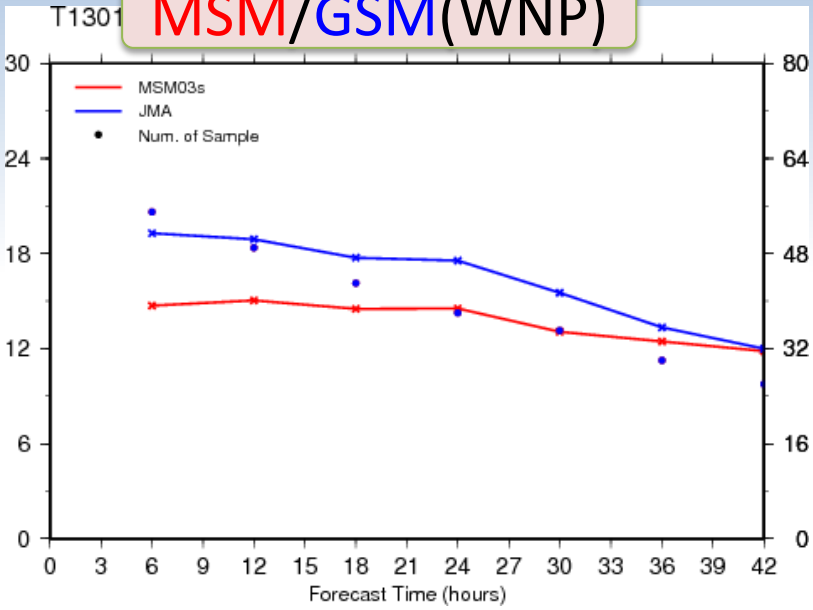
ALADIN/IFS(NAT)



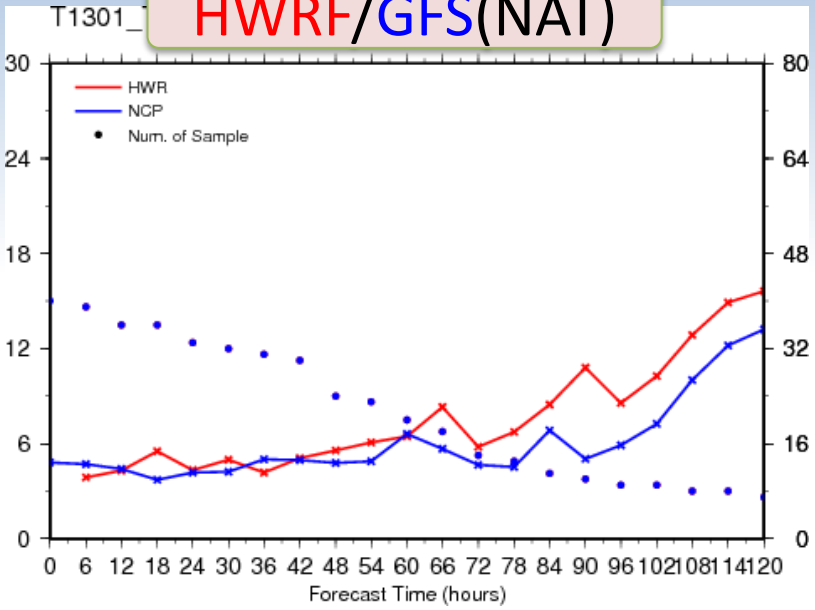
In this season number of TC samples is very few in AUR and NAT region.
Roughly speaking, position error of regional model is almost as same as that of global model.

Intensity RMSE of homogeneous samples

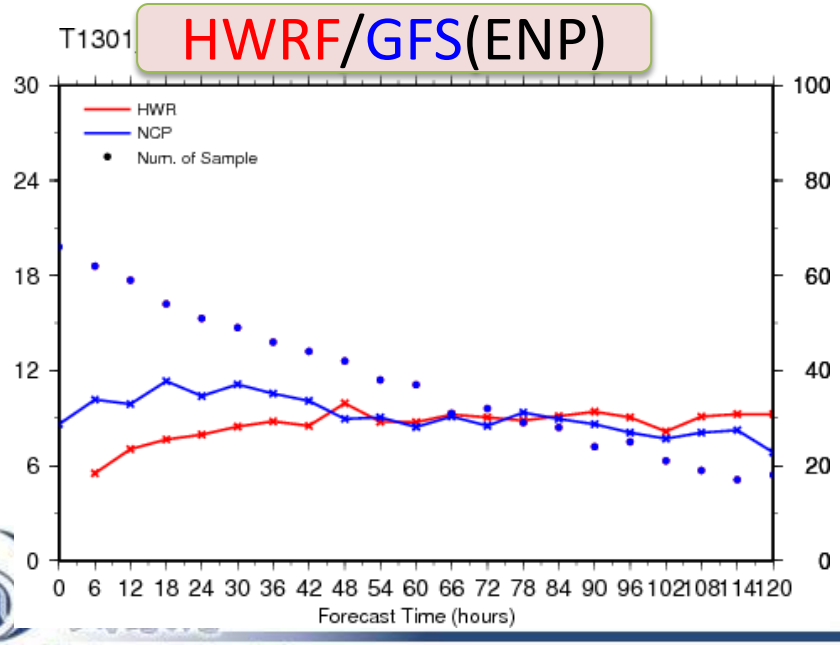
MSM/GSM(WNP)



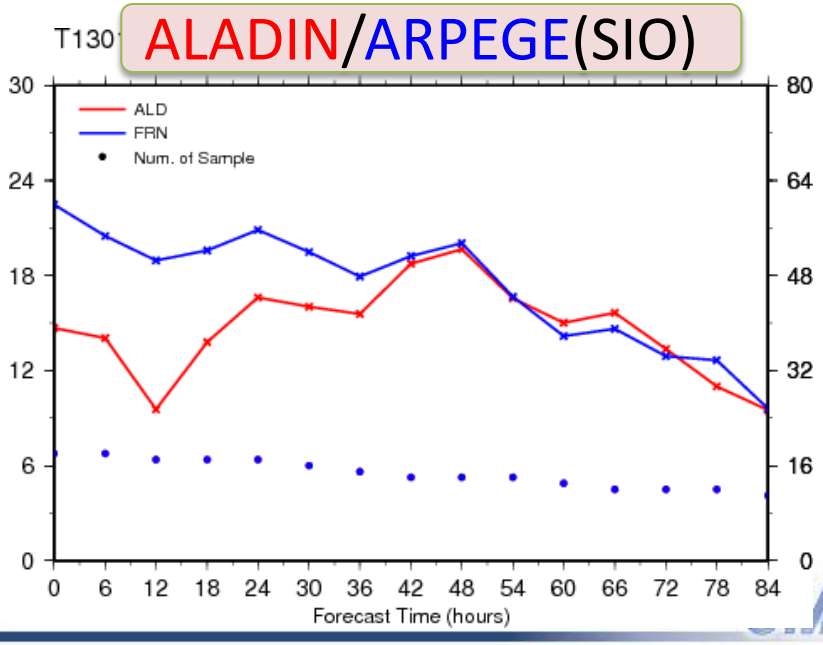
HWRF/GFS(NAT)



HWRF/GFS(ENP)

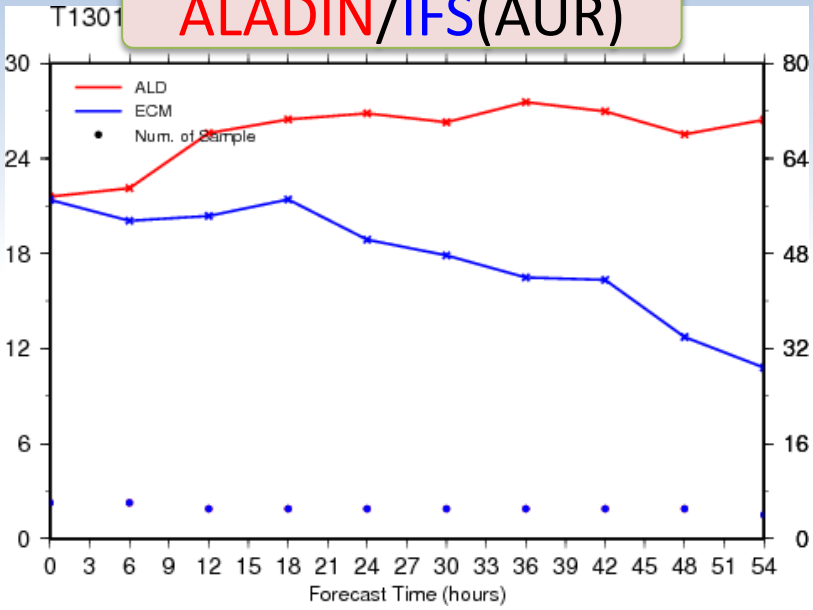


ALADIN/ARPEGE(SIO)

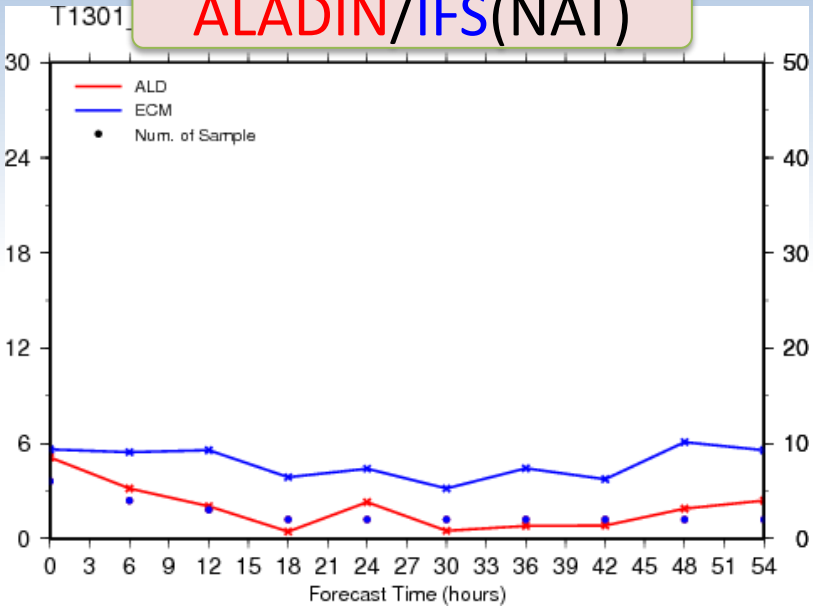


Intensity RMSE of homogeneous samples

ALADIN/IFS(AUR)



ALADIN/IFS(NAT)



Some regional models show that its intensity RMSE is smaller than that of the global model which provides LBC to it especially in the beginning of forecast.

ADDITIONAL VERIFICATION

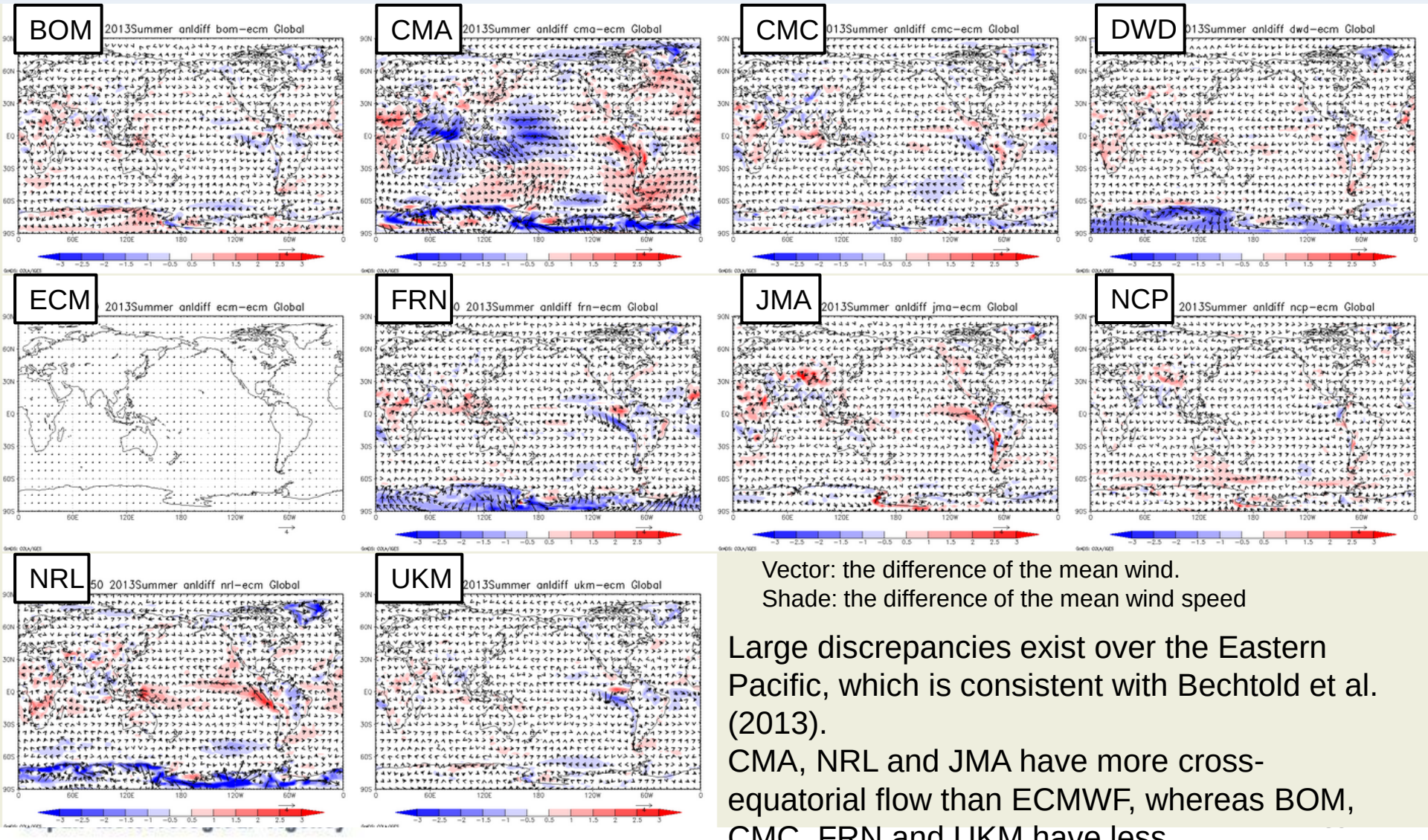
Verification using 850 hPa winds

Motivation and Methodology

- Wind fields in the Tropics are uncertain due to the limited observation.
- How do the tropical winds in the analyses differ between the models?
- What kinds of bias in the wind fields do the models have? Is there any common feature?

- Data: Wind fields at 850 hPa. The forecasts initiated at 12 UTC each day are verified.
- Period: Boreal summer (May-Nov. 2013.)

Difference of wind fields in the analyses compared to ECMWF

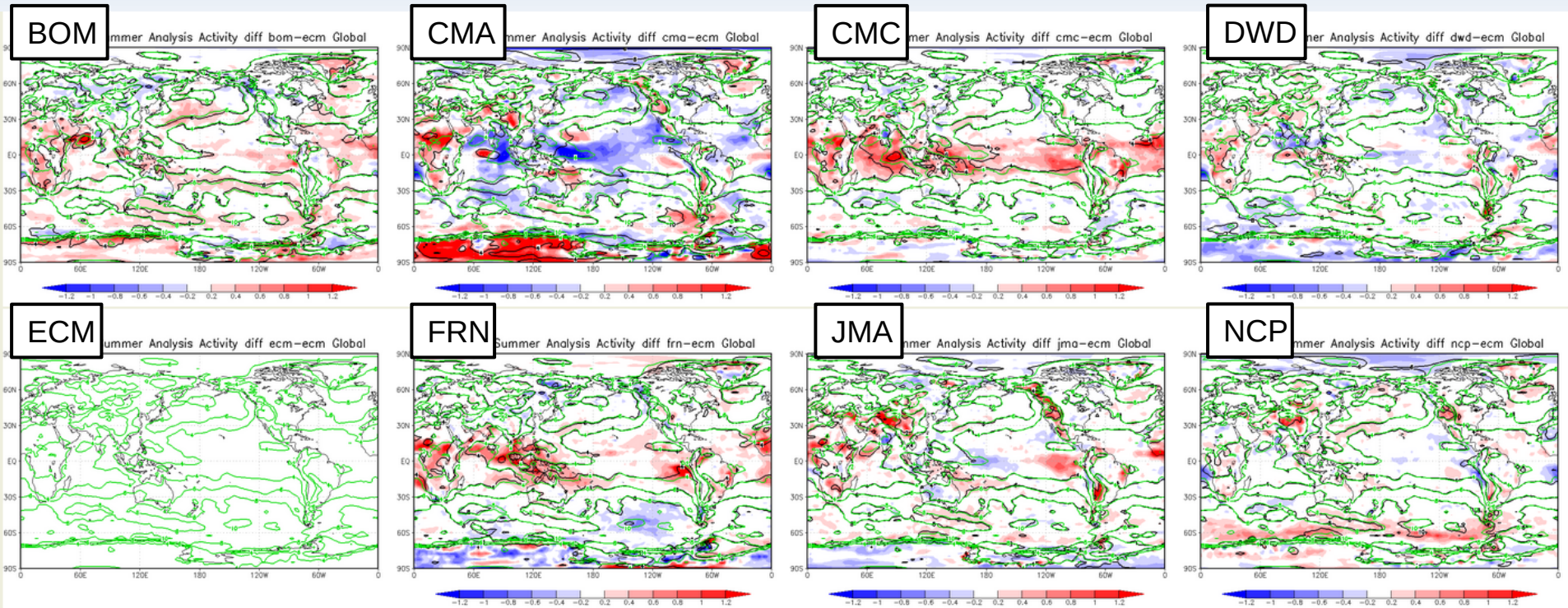


Vector: the difference of the mean wind.
Shade: the difference of the mean wind speed

Large discrepancies exist over the Eastern Pacific, which is consistent with Bechtold et al. (2013).

CMA, NRL and JMA have more cross-equatorial flow than ECMWF, whereas BOM, CMC, FRN and UKM have less.

Difference of analysis activities compared to ECMWF



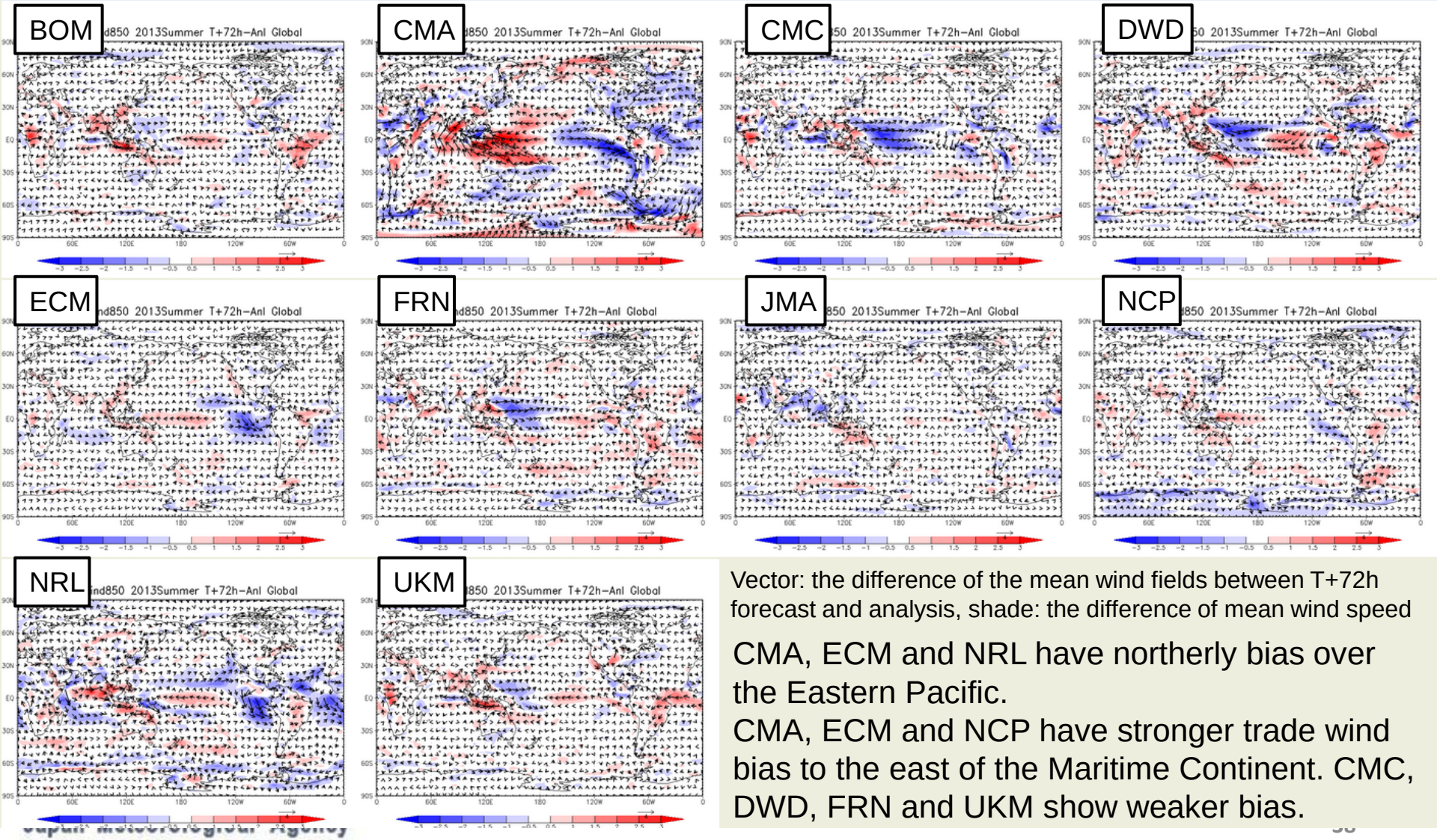
Black contour: own model, green contour: ECMWF
Shade: the difference between them

BOM, CMC, FRN and NRL have generally higher activities than ECMWF in the tropics. CMA shows weaker variability, while the other centers are comparable.

$$AA = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(A_i - C_i)^2}$$

A: Analysis
C: Climatology

Model forecast biases in the wind fields based on their own analyses

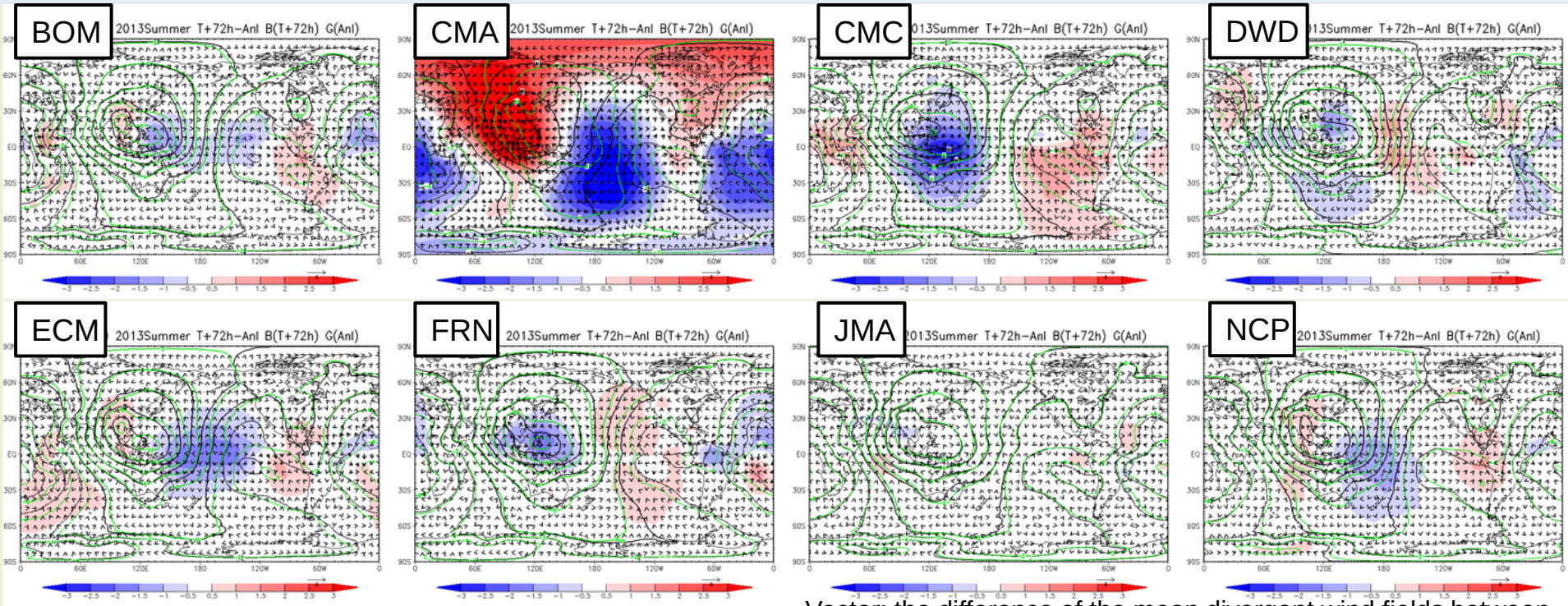


Vector: the difference of the mean wind fields between T+72h forecast and analysis, shade: the difference of mean wind speed

CMA, ECM and NRL have northerly bias over the Eastern Pacific.

CMA, ECM and NCP have stronger trade wind bias to the east of the Maritime Continent. CMC, DWD, FRN and UKM show weaker bias.

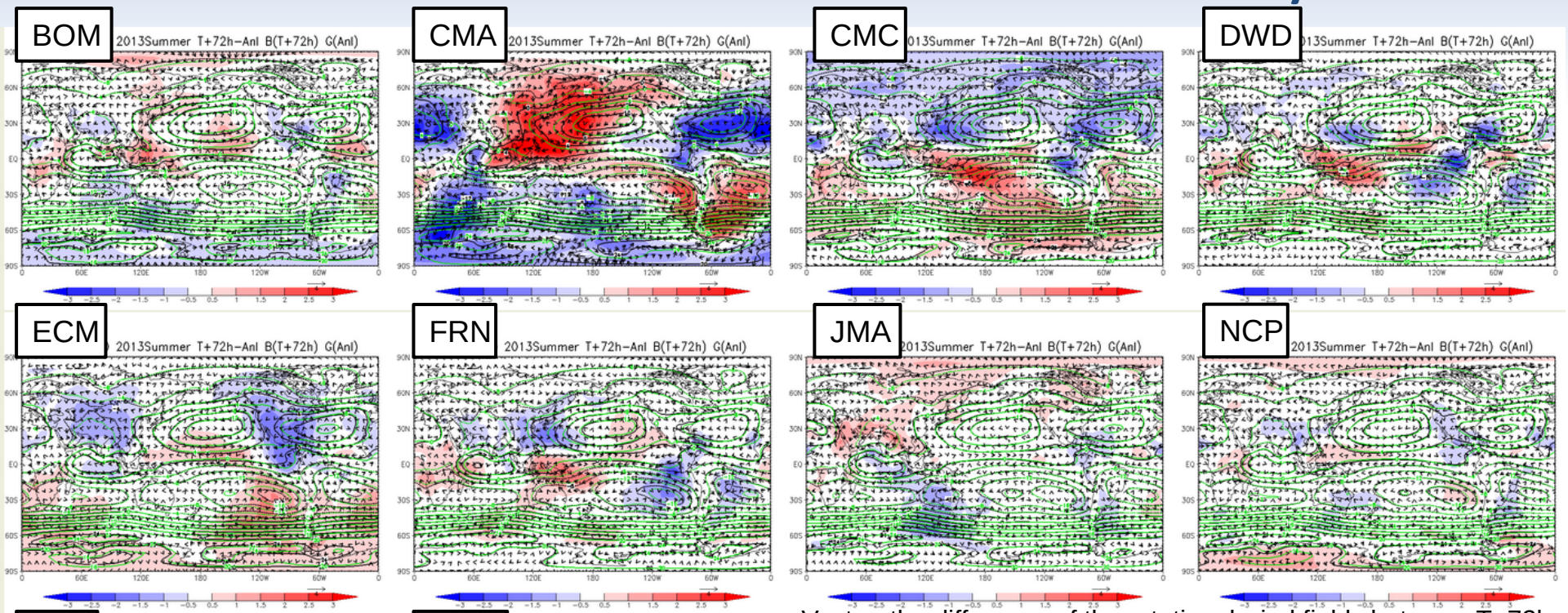
Model forecast biases in the divergent wind fields based on their own analyses



Vector: the difference of the mean divergent wind fields between T+72h forecast and analysis.
Shade: the difference of the velocity potential (x10^6 m^2/s) between T+72h and analysis.
Black contour: velocity potential at T+72h, green: at analysis

BOM, CMA, ECM, NCP and UKM shows lower potential bias over the Western Pacific, and higher over the Southeast Asia. CMC, DWD and FRN have lower potential bias over the Maritime Continent.

Model forecast biases in the rotational wind fields based on their own analyses



Vector: the difference of the rotational wind fields between T+72h forecast and analysis.
Shade: the difference of the stream function (x10^6 m^2/s) between T+72h and analysis.
Black contour: stream function at T+72h, green: at analysis

CMC, DWD, FRN and UKM show similar pattern in the bias of stream function to the east of the Maritime Continent, and westerly wind bias.

Brief comment

- Large discrepancies in the analyses exist over the Eastern Pacific.
- Several models have forecast bias over the Eastern Pacific and Western Pacific, which seems partly due to the difficulty in maintaining the convective activity over the Maritime Continent.

Reference

- Bechtold, P., P. Bauer, J.-R. Bidlot, C. Cardinali, L. Magnusson, F. Prates and M. Rodwell, 2013: Uncertainty in tropical winds. ECMWF News Letter, 134, 33-37.

ADDITIONAL VERIFICATION

Selective Ensemble Mean
for Tropical Cyclone Track Forecasting

Selective Ensemble Mean for Tropical Cyclone Track Forecasting

1. Introduction:

- Selective ensemble mean technique, in **which larger weights are given to ensemble members close to observations at short lead times (e.g., 6 hours)**, for tropical cyclone track forecasting is investigated.
- The slowness of availability time of ensemble forecasts, which is due mainly to the required large computational resources, makes it possible to utilize the observations.

2. Main Results:

- **Selective ensemble mean approach is better than simple ensemble mean approach**, but has only limited effects when compared with the best single model forecasts that are ECMWF deterministic forecasts.
- However selective ensemble mean approach shows the best performance for cases where the ensemble spread at short lead time (e.g., 6 hours) is large.
- In general, **best performance has been obtained from a simple ensemble mean of ECMWF and NCEP**.

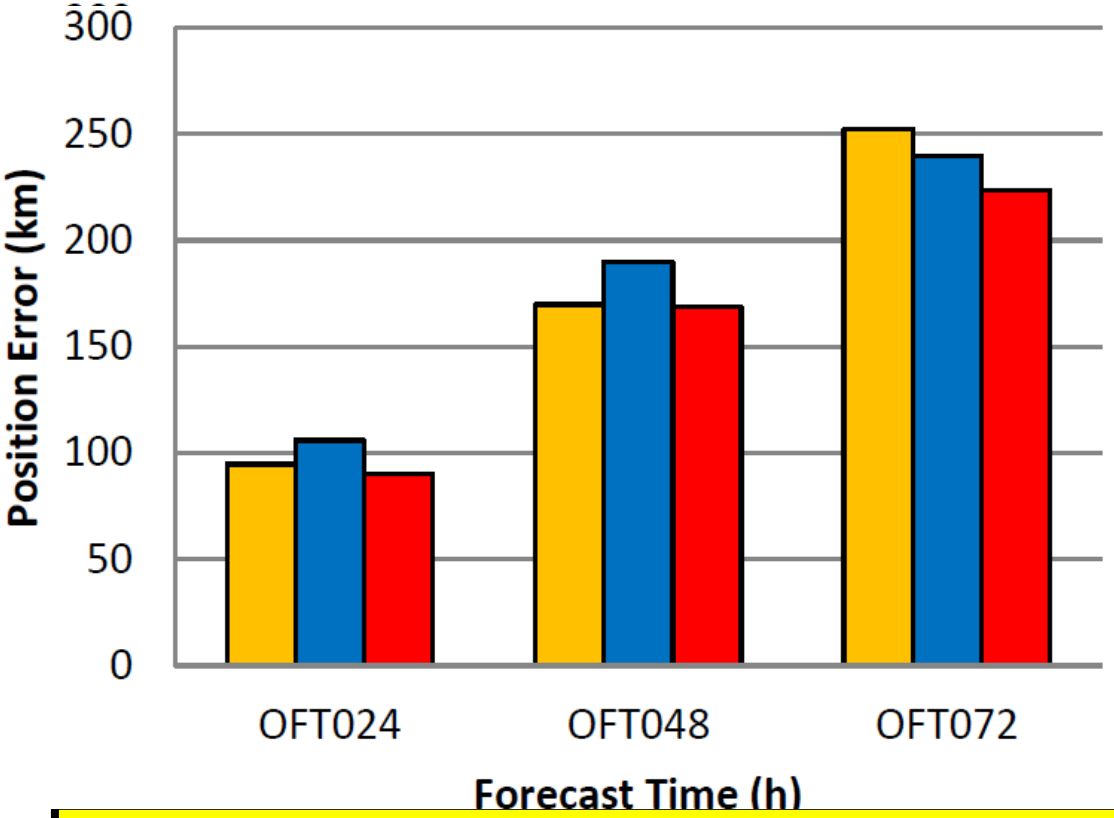
3. Future plan

- Planning to submit a paper to an international journal (e.g., Tropical Cyclone Research and Review).

Results (1/2)

Samples with large ensemble spread

(2010 – 2013, North Western Pacific Basin)



Yellow

ECMWF Deterministic Forecasts

Blue

Simple ensemble mean

Red

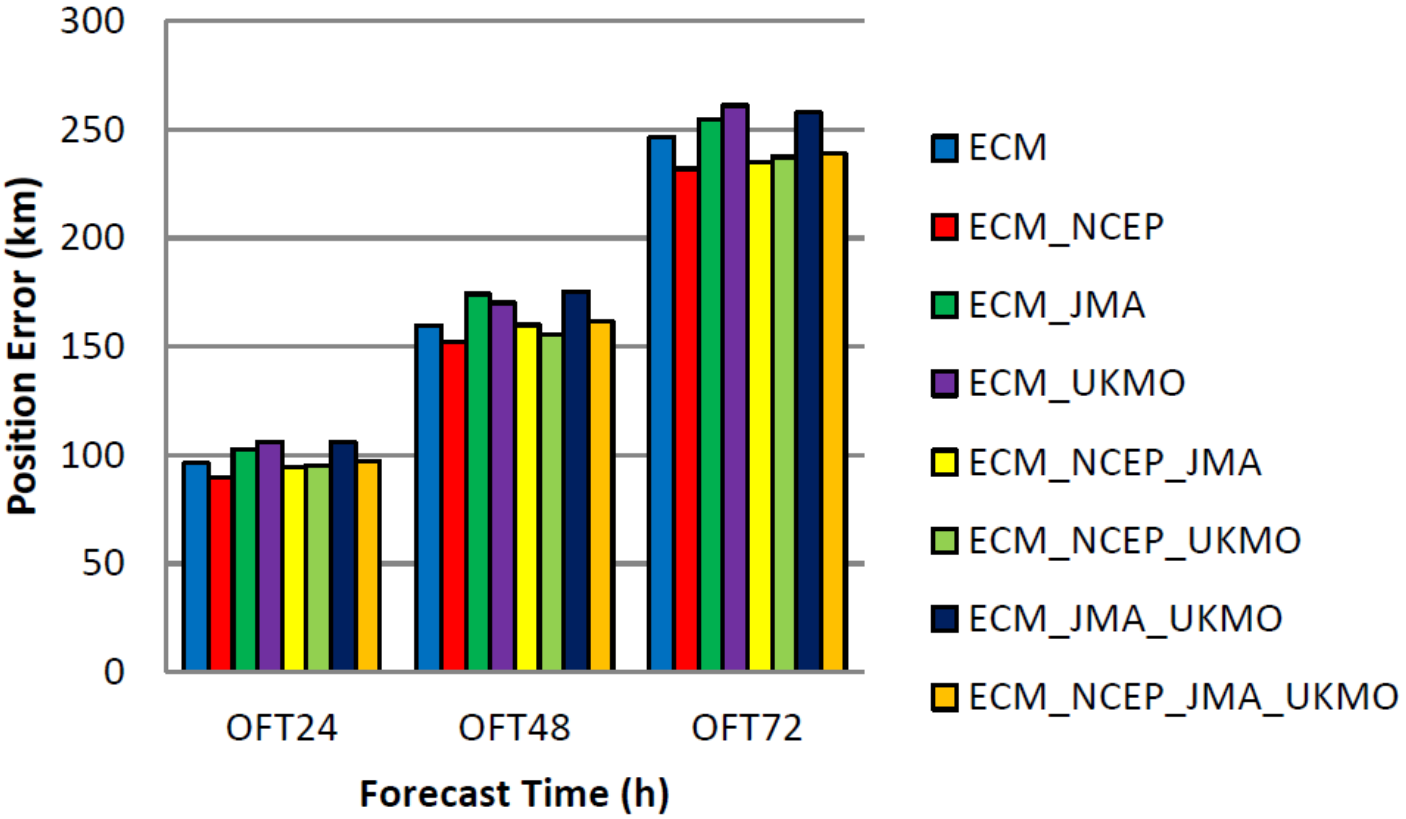
Selective ensemble mean

•The position error of selective ensemble mean is smaller than that of simple

•If the verification samples are limited to cases with large ensemble spread at a short lead time, selective ensemble mean approach shows the best performance.

Results (2/2)

Simple ensemble mean using ECMWF, JMA, NCEP, UKMO ensembles (2010 – 2013, North Western Pacific Basin)

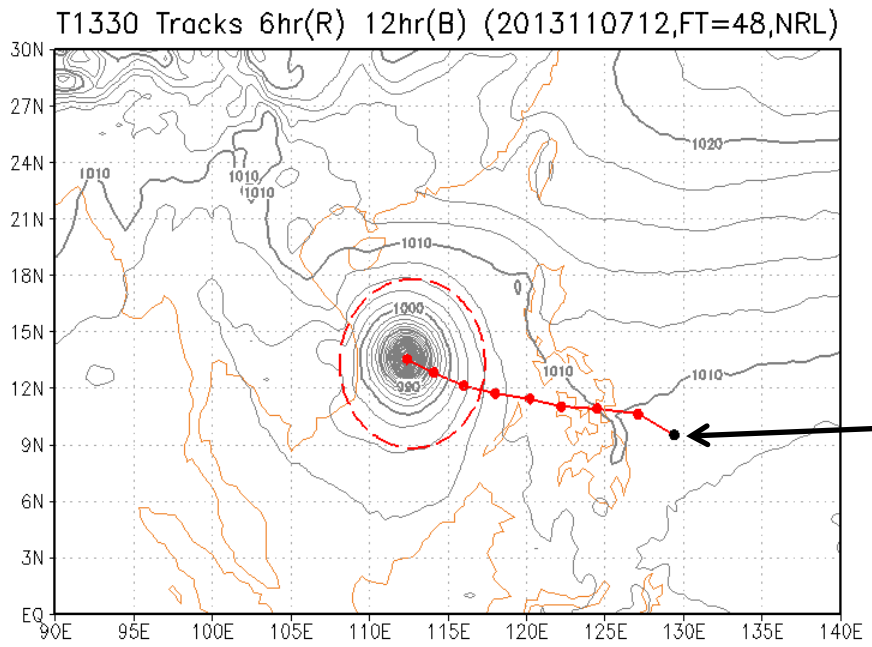


•A simple ensemble mean of ECMWF and NCEP shows the best performance for all verification samples from 2010 to 2013 over the North Western Pacific basin.

BACKUP SLIDES

Dependencies of verification result on the spatial and temporal resolution of forecast GPVs

Using 6-hourly forecast instead of 12-hourly forecast



Forecast of Typhoon Haiyan
(NRL, Initial: 12UTC 7 November, 2013)

Red: forecast track with 6-hourly GPV
Black: forecast track with 12-hourly GPV
Circle: search range (500km radius) of central position of each track

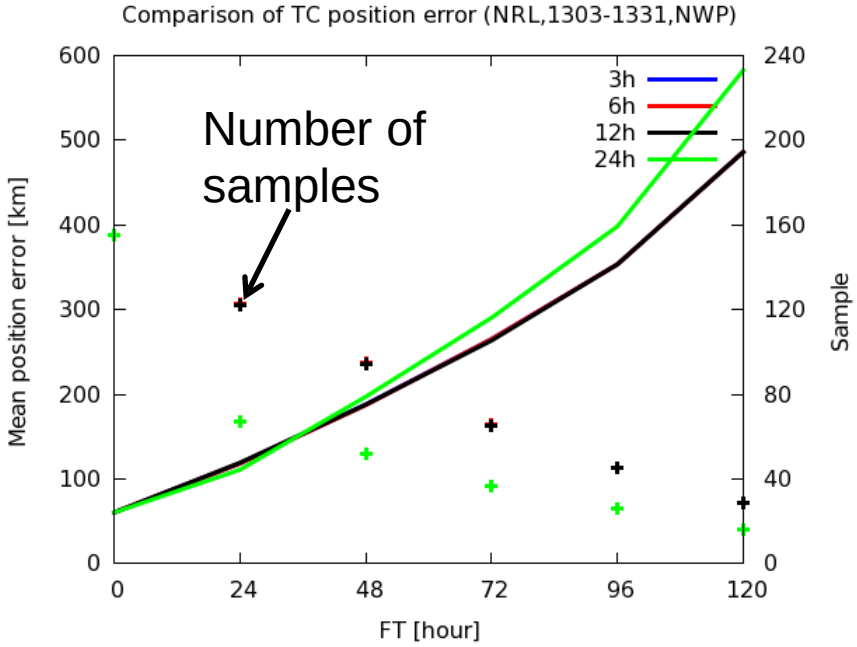
Both tracks start from the same position (close enough to the besttrack position)

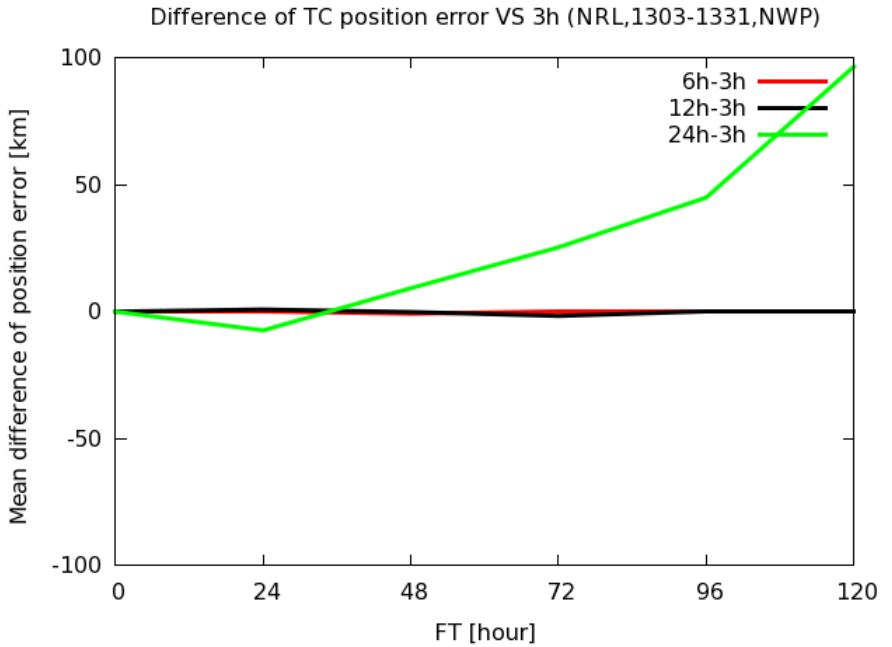
At FT=6, red track found TC center within 500km search range

At FT=12, black track tried to find TC center within 500km from the initial position, but failed. Red track could find it within 500km radius circle centered on the first-guess position determined from the positions at FT=0 and 6.

Initial tracking will be failed if TC moves faster than
500km / 6h ~ 83 km/h from FT=0 to FT=6 for 6-hourly track
500km / 12h ~ 42 km/h from FT=0 to FT=12 for 12-hourly track

Using 6-hourly forecast instead of 12-hourly forecast



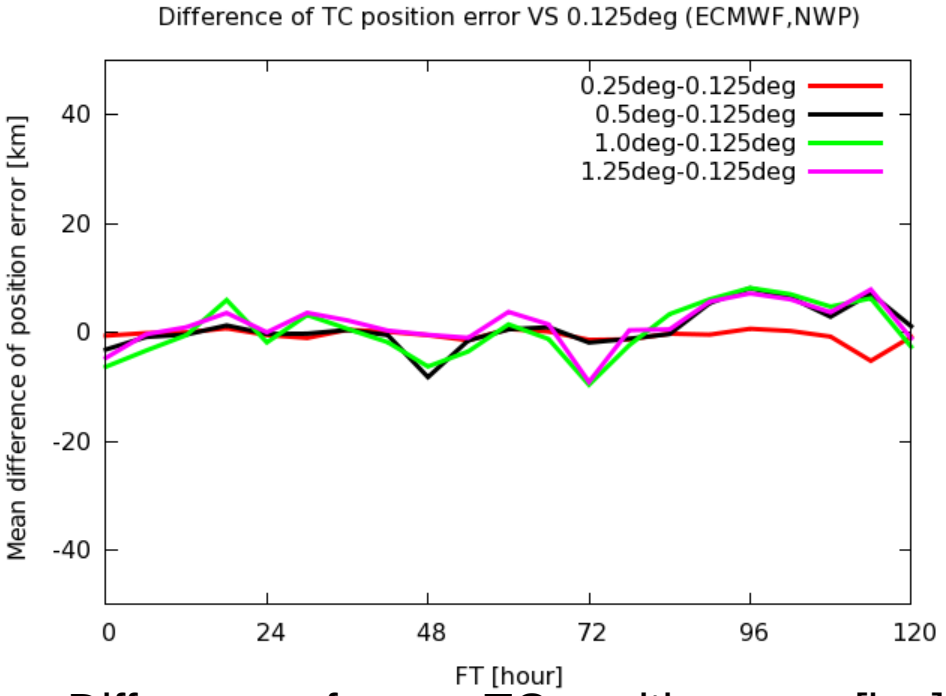


Mean position error [km] of TC forecast track using 3, 6, 12 and 24 hourly GPV (NRL, WNP basin, T1303-T1331)

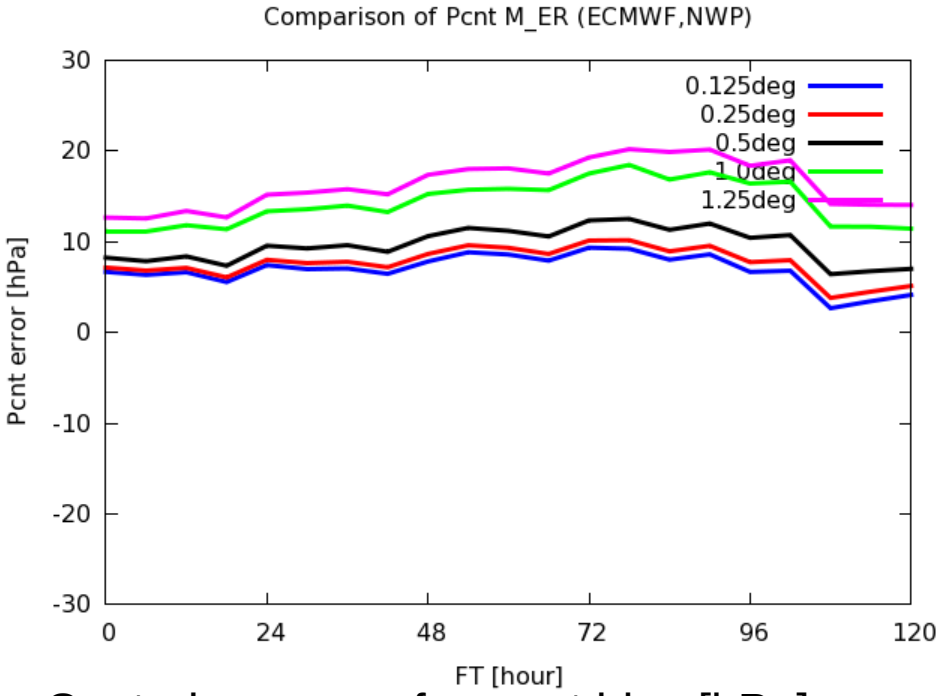
Difference of mean position error [km] from that of 3 hourly TC track
Inhomogeneous sample

There is no discernable difference among mean position errors of 3, 6 and 12 hourly TC track

Dependency on horizontal resolution



Difference of mean TC position error [km] using various horizontal resolution (vs 0.125 deg., ECMWF, WNP basin)

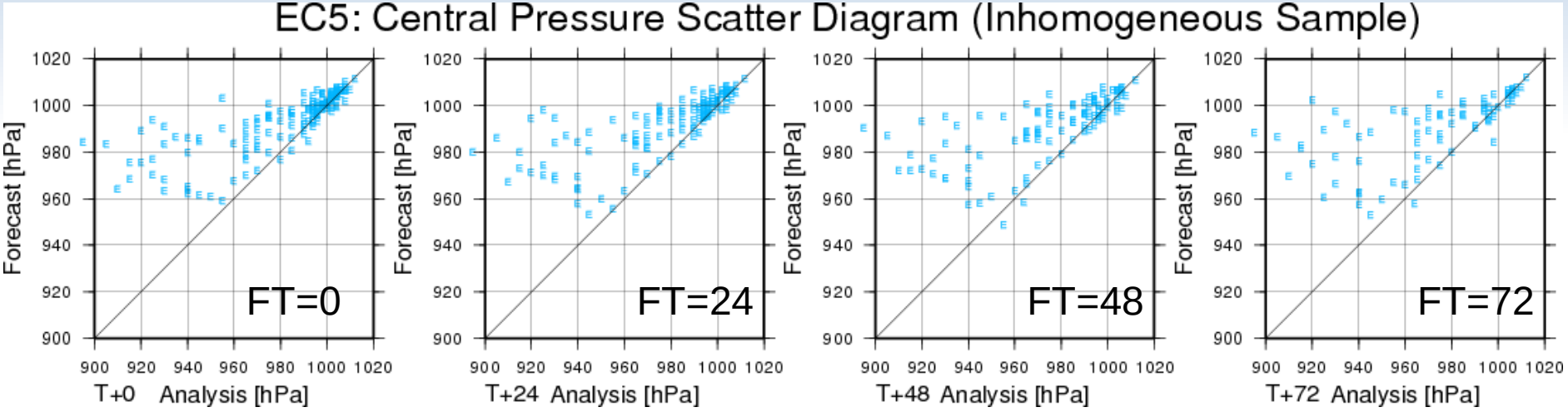


Central pressure forecast bias [hPa] using various horizontal resolution

Homogeneous sample

- There is little dependency on the horizontal resolution for mean TC position error.
- Large systematic dependency on the horizontal resolution for central pressure forecast.
  - Larger bias for coarser resolution.

Dependency on horizontal resolution



Resolution: 1.25 degree

Scatter plot of central pressure forecast (vertical axis) and the analyzed central pressure (horizontal axis). (ECMWF, WNP basin)

- Central pressure forecast bias for strong TCs is increased when the horizontal resolution changes from 0.125 degrees to 0.25 degrees.

- Using the coarser GPVs resulted in larger central pressure forecast bias.
- We need special cautions when comparing the TC intensity bias using GPVs with different horizontal resolution.

BACKUP SLIDES 2

Comparison of cyclone density in Tropics

Cyclone detection using 850 hPa winds

1. Detection method

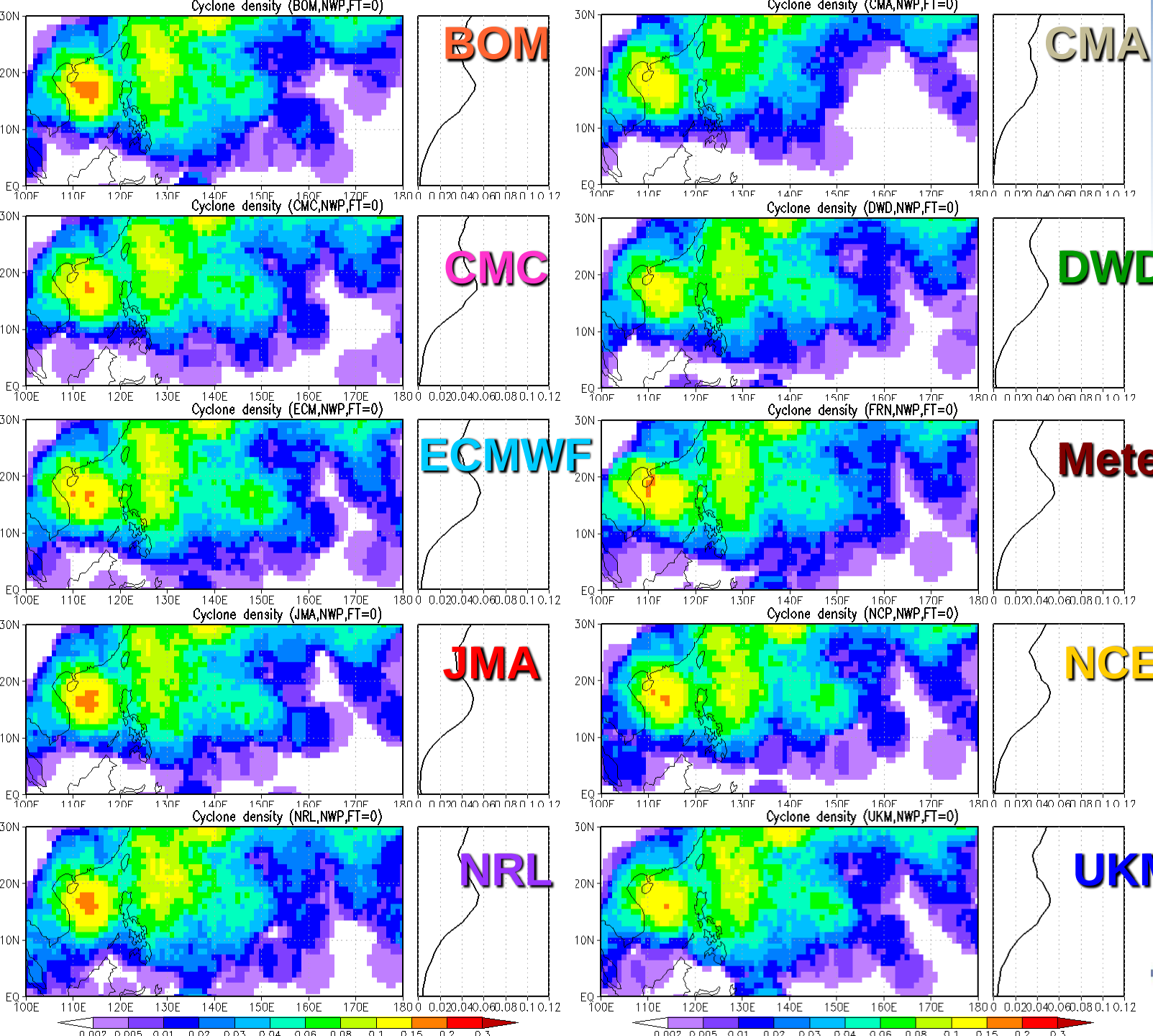
1) Interpolate all forecast fields to 1.25x1.25 lat-lon grids
2) Search grid points where
   - mean sea-level pressure (MSLP) becomes minimum within 500 km radius,
   - its minimum value is at least 0.5 hPa less than average MSLP within 500 km radius, and
   - average 850 hPa relative vorticity within 300 km is larger than 30×10^{-6} s^{-1} (opposite sign for Southern Hemisphere)

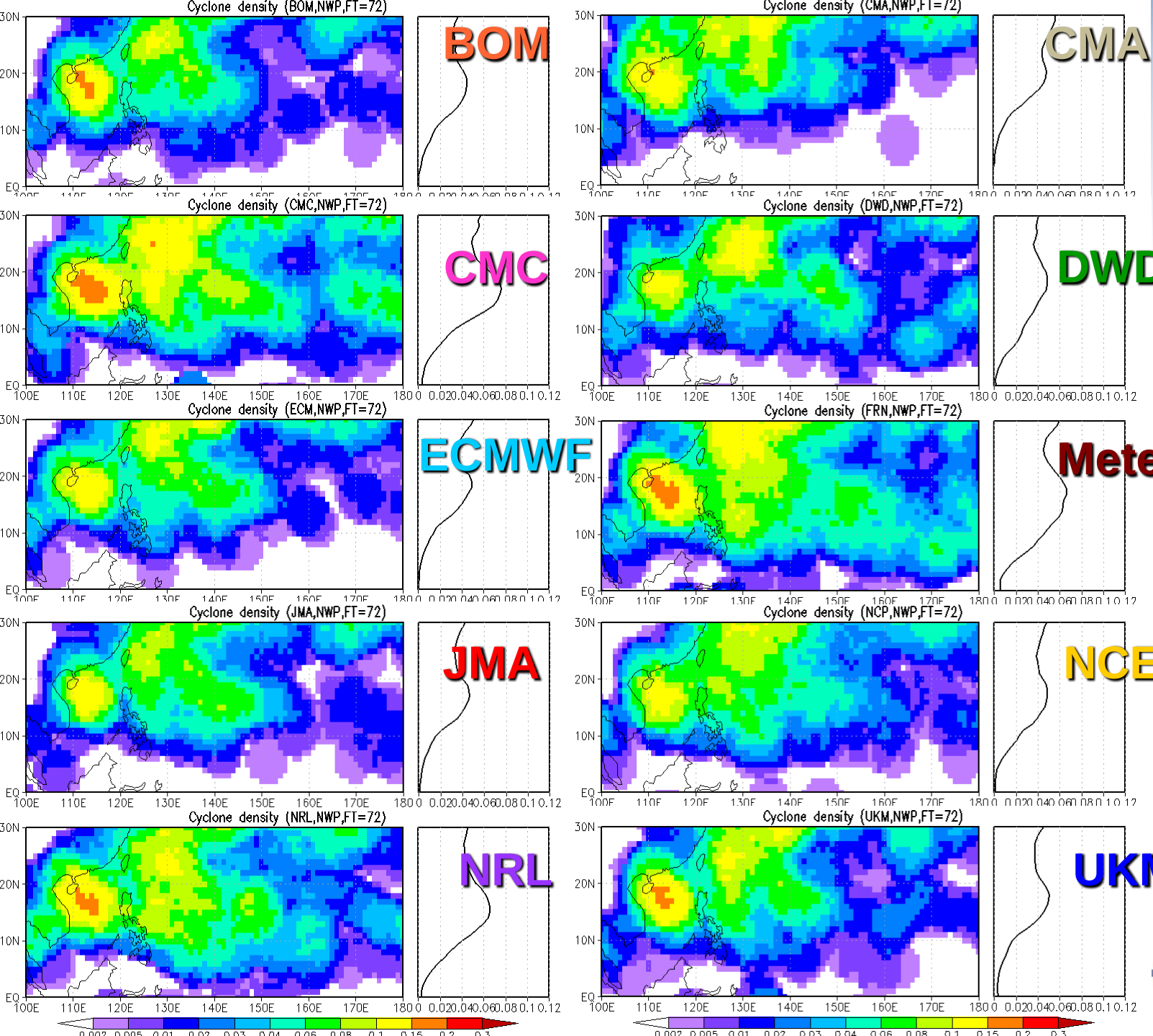
2. Verification method

Compare the average number of forecast cyclone center positions within 500 km

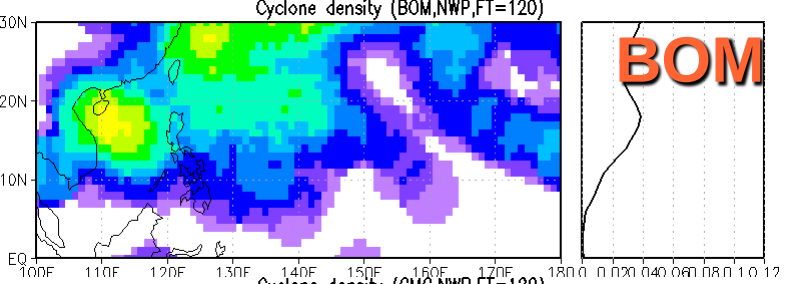
3. Periods

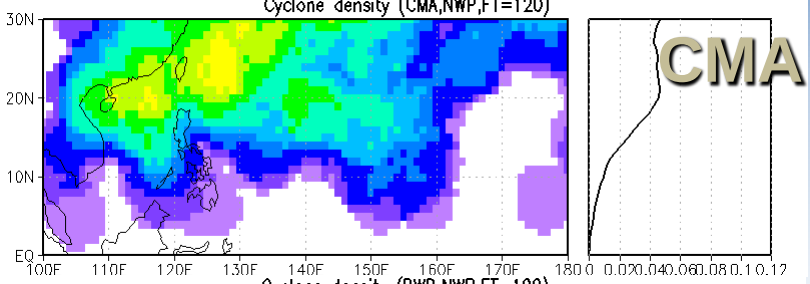
Northern Hemisphere: from May 1, 2013 to November 30, 2013
Southern Hemisphere: from December 1, 2012 to March 31, 2013


Cyclone density (BOM,NWP,FT=0)
BOM
Cyclone density (CMA,NWP,FT=0)
CMA
WNP
domain
FT=0
Cyclone density (CMC,NWP,FT=0)
CMC
Cyclone density (DWD,NWP,FT=0)
DWD
Cyclone density (ECM,NWP,FT=0)
ECMWF
Cyclone density (FRN,NWP,FT=0)
Meteo France
Cyclone density (JMA,NWP,FT=0)
JMA
Cyclone density (NCP,NWP,FT=0)
NCEP
Cyclone density (NRL,NWP,FT=0)
NRL
Cyclone density (UKM,NWP,FT=0)
UKMO
30N
20N
10N
EQ
100E 110E 120E 130E 140E 150E 160E 170E 180
0 0.02 0.04 0.06 0.08 0.1 0.12
0.002 0.005 0.01 0.02 0.03 0.04 0.06 0.08 0.1 0.15 0.2 0.3

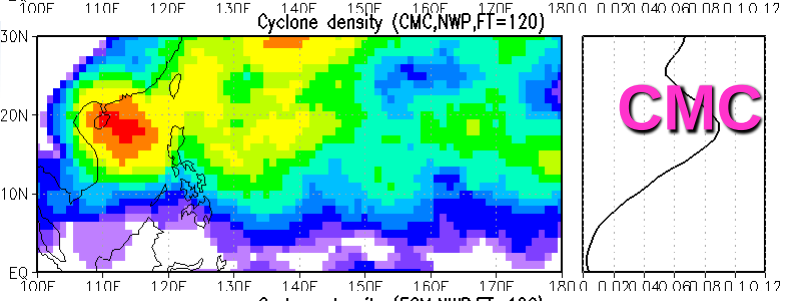


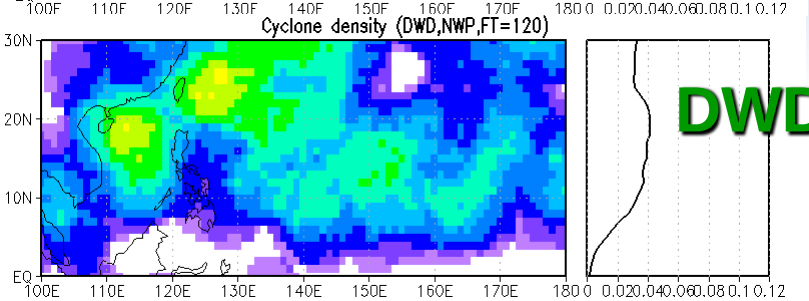
WNP domain FT=72

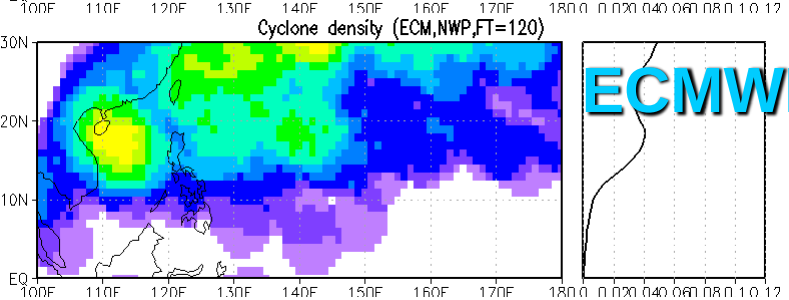




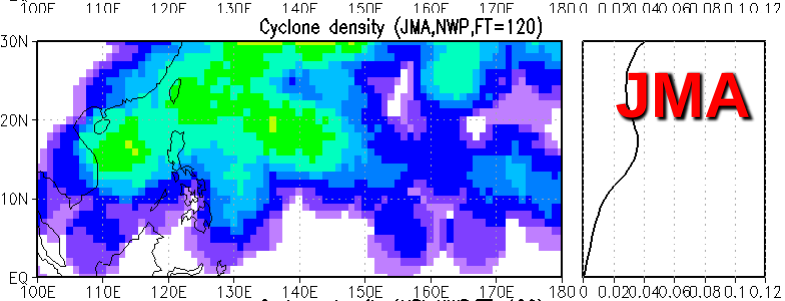
WNP domain FT=120

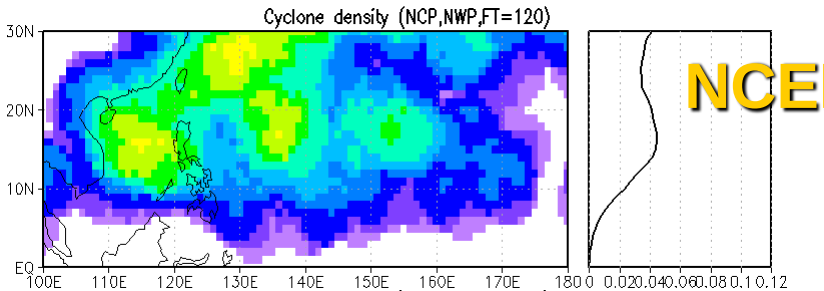


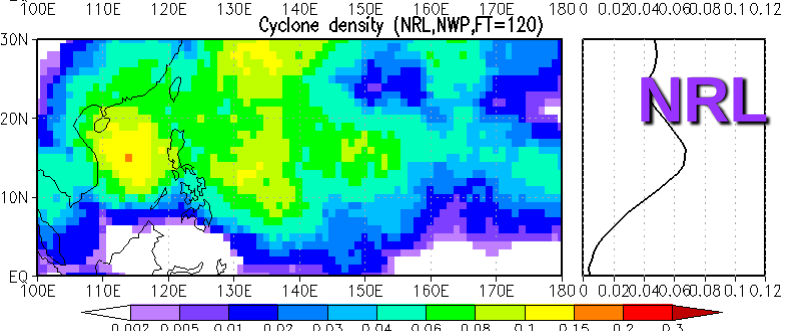


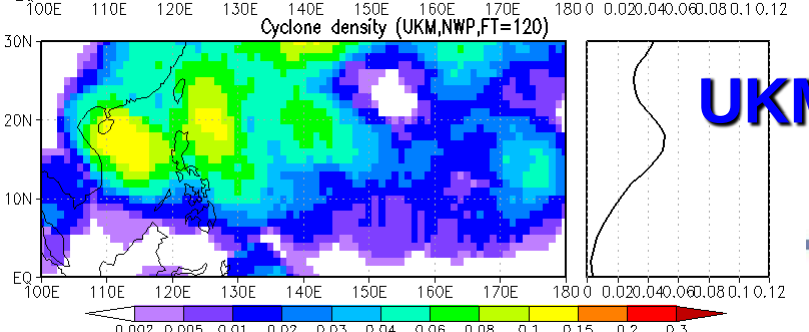


Meteo France

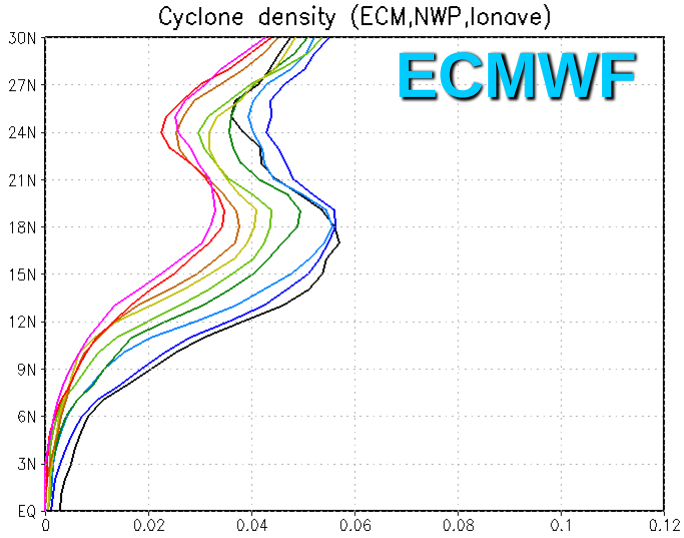


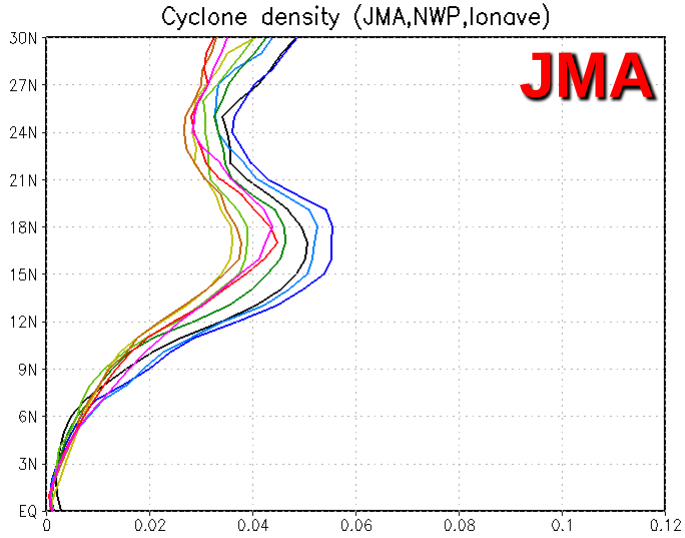


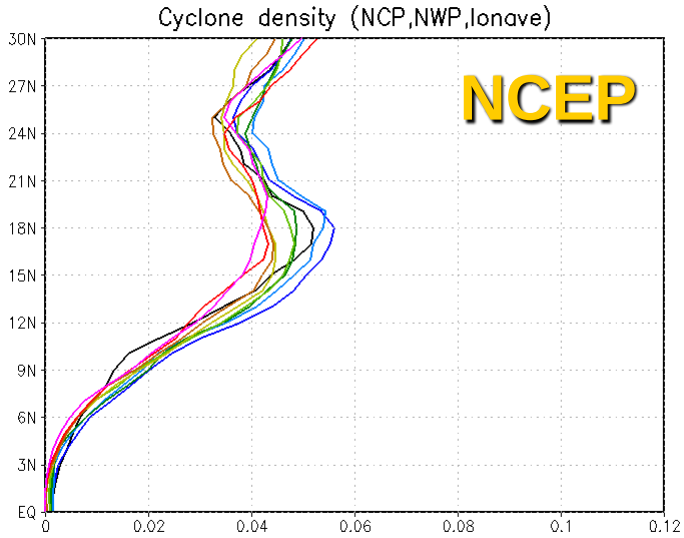


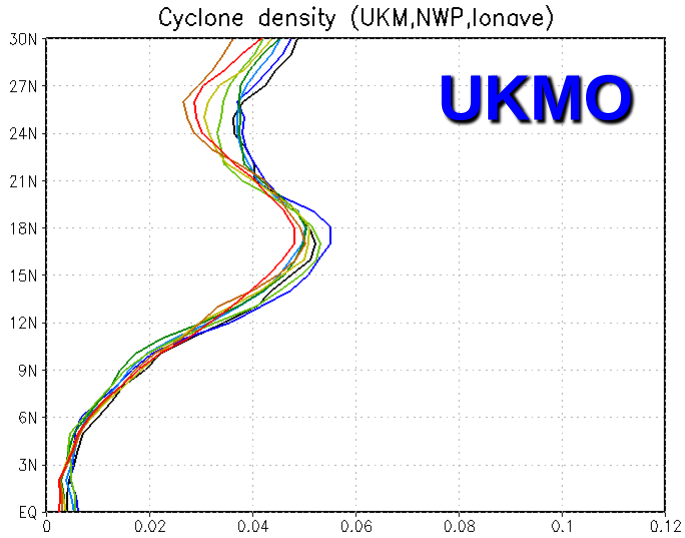


Comparison of 4 NWP centers (WNP)

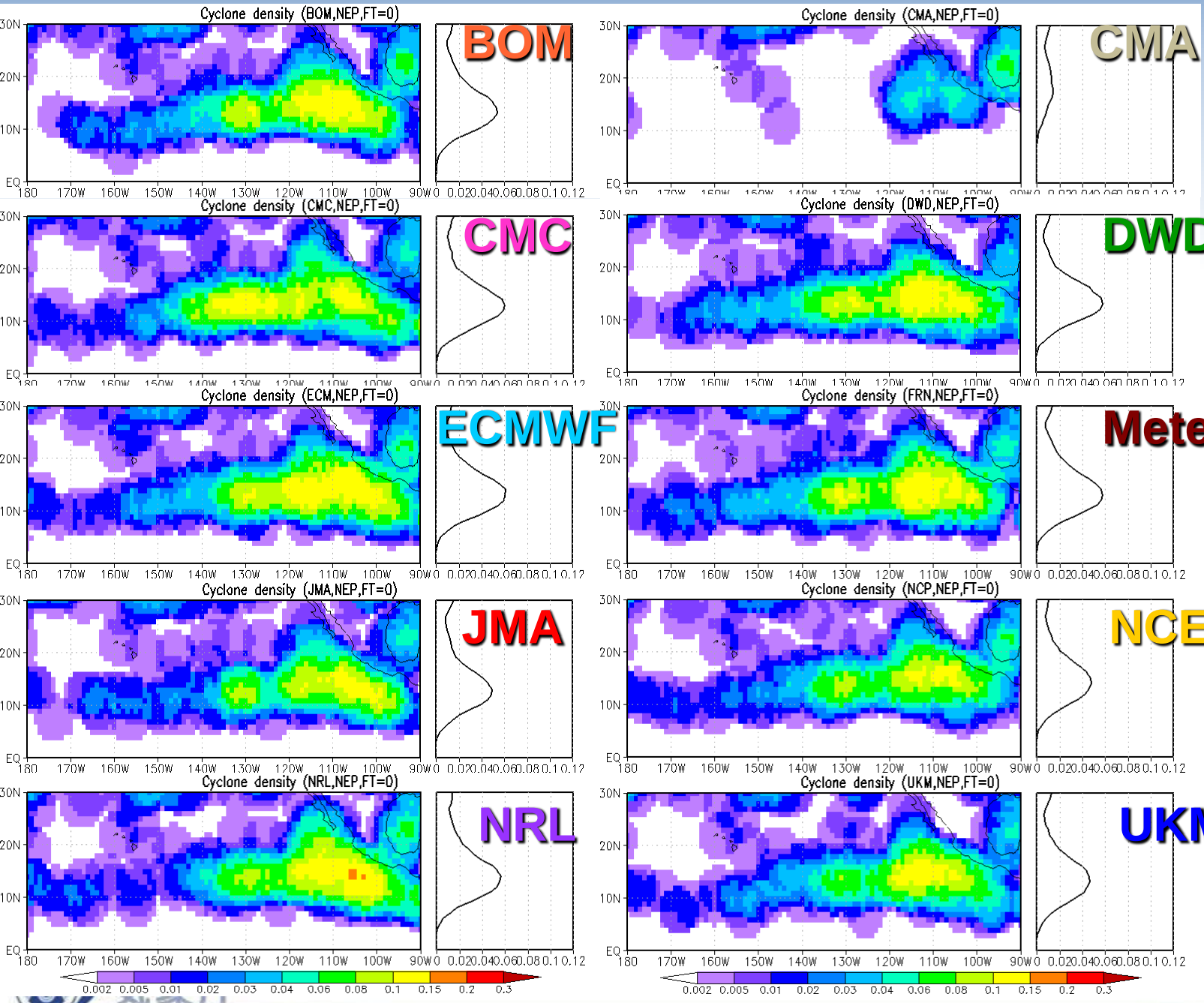


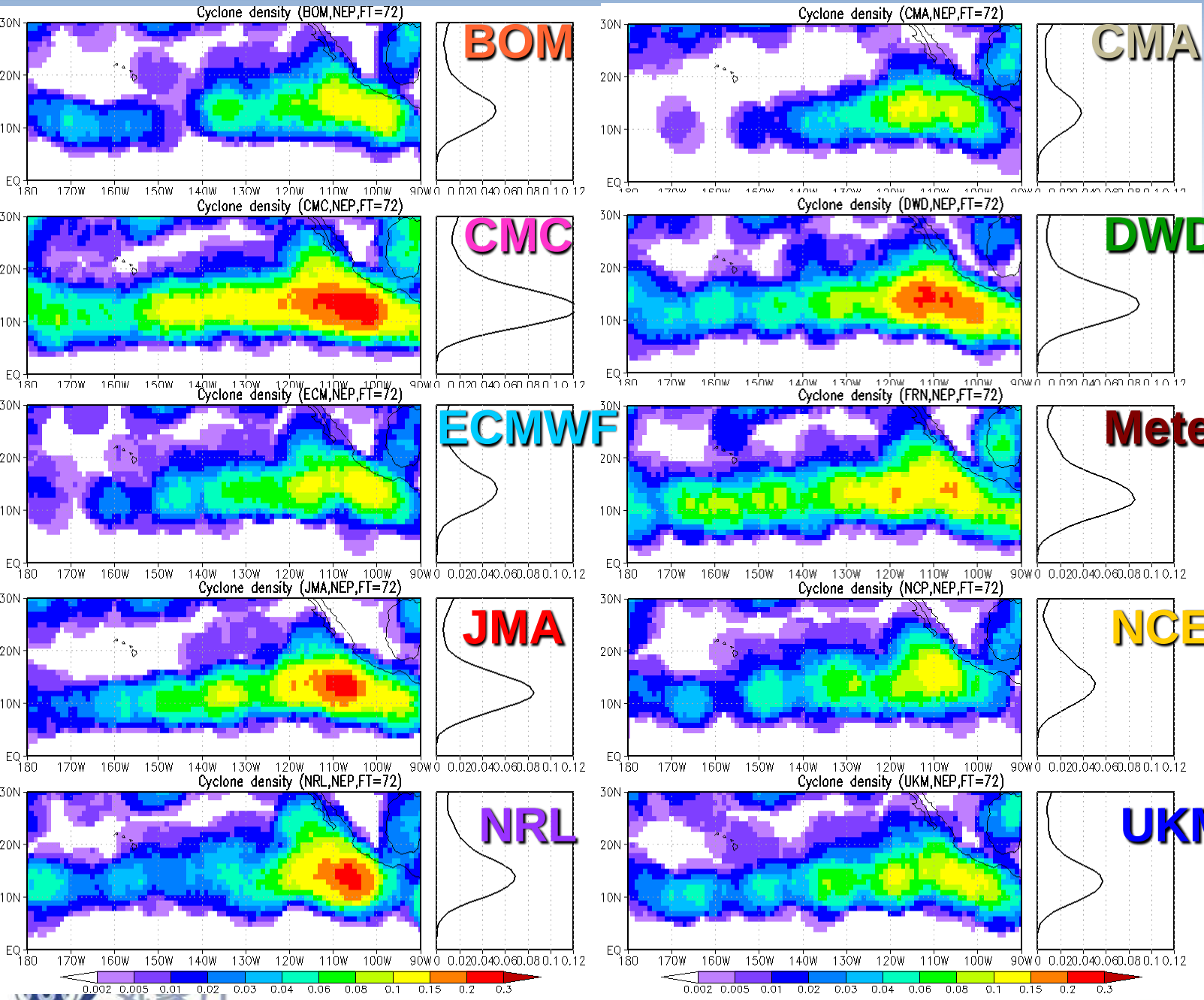


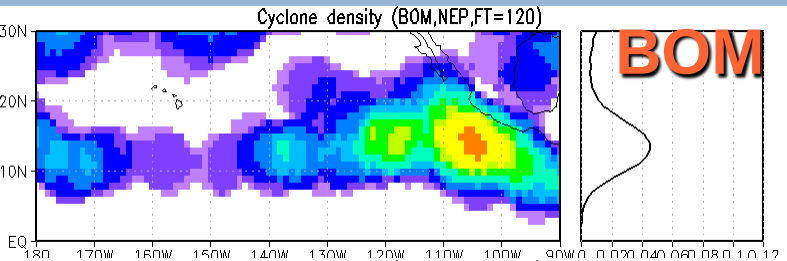




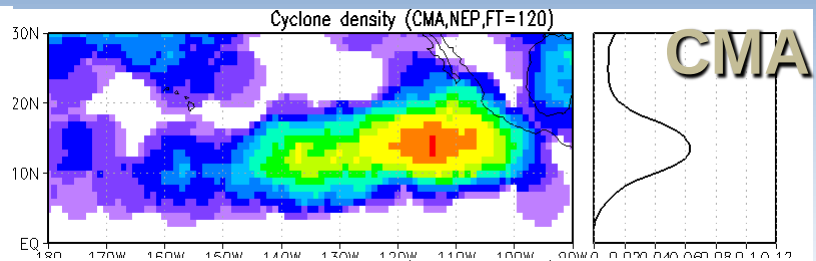
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192


Cyclone density (BOM,NEP,FT=0)
BOM
Cyclone density (CMA,NEP,FT=0)
CMA
ENP domain
Cyclone density (CMC,NEP,FT=0)
CMC
Cyclone density (DWD,NEP,FT=0)
DWDFT=0
Cyclone density (ECM,NEP,FT=0)
ECMWF
Cyclone density (FRN,NEP,FT=0)
Meteo France
Cyclone density (JMA,NEP,FT=0)
JMA
Cyclone density (NCP,NEP,FT=0)
NCEP
Cyclone density (NRL,NEP,FT=0)
NRL
Cyclone density (UKM,NEP,FT=0)
UKMO
30N
20N
10N
EQ
180 170W 160W 150W 140W 130W 120W 110W 100W 90W
0 0.02 0.04 0.06 0.08 0.1 0.12
0.002 0.005 0.01 0.02 0.03 0.04 0.06 0.08 0.1 0.15 0.2 0.3


Cyclone density (BOM,NEP,FT=72)
BOM
Cyclone density (CMA,NEP,FT=72)
CMA
ENP domain FT=72
Cyclone density (CMC,NEP,FT=72)
CMC
Cyclone density (DWD,NEP,FT=72)
DWD
Cyclone density (ECM,NEP,FT=72)
ECMWF
Cyclone density (FRN,NEP,FT=72)
Meteo France
Cyclone density (JMA,NEP,FT=72)
JMA
Cyclone density (NCP,NEP,FT=72)
NCEP
Cyclone density (NRL,NEP,FT=72)
NRL
Cyclone density (UKM,NEP,FT=72)
UKMO
0.002 0.005 0.01 0.02 0.03 0.04 0.06 0.08 0.1 0.15 0.2 0.3

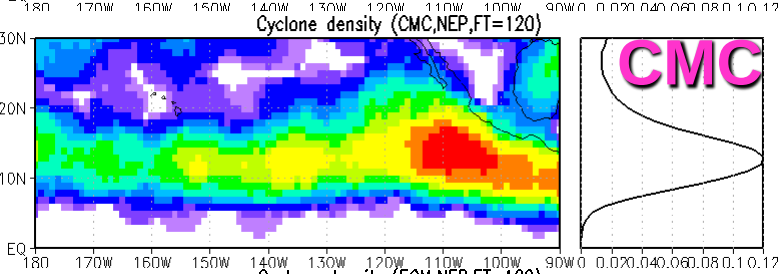


BOM

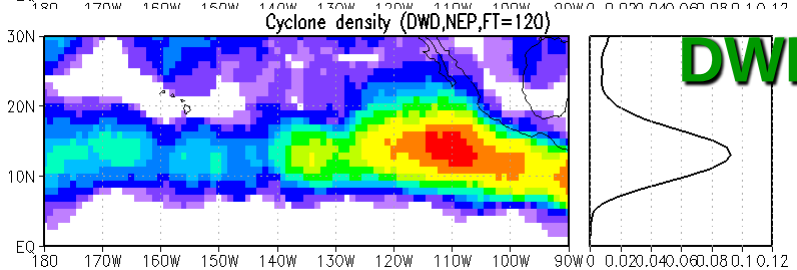


CMA

ENP domain

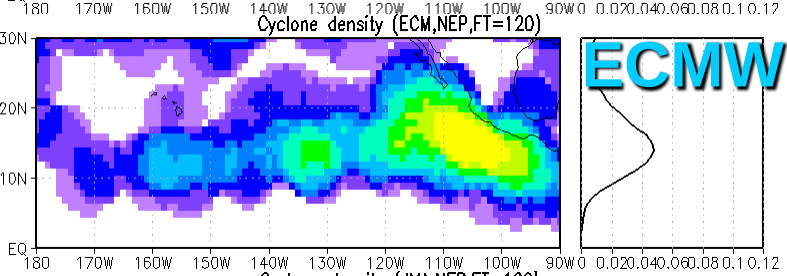


CMC



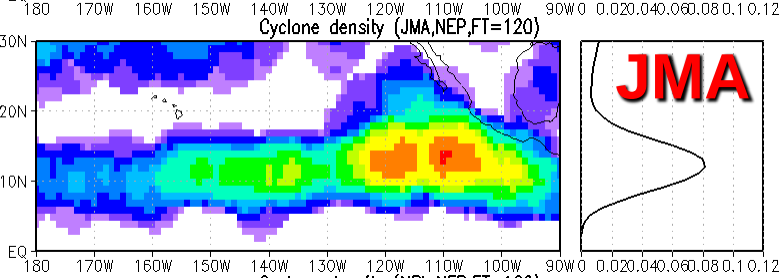
DWD

FT=120

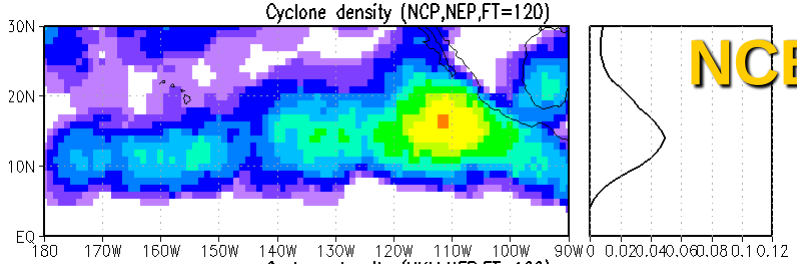


ECMWF

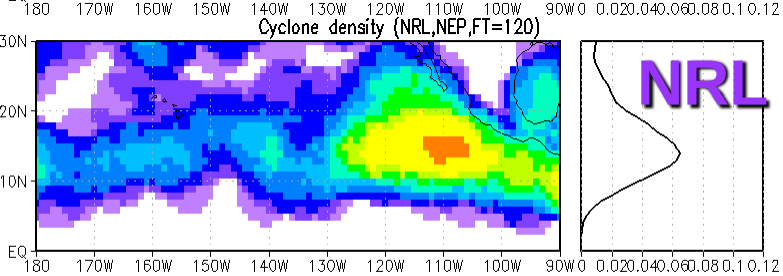
Meteo France



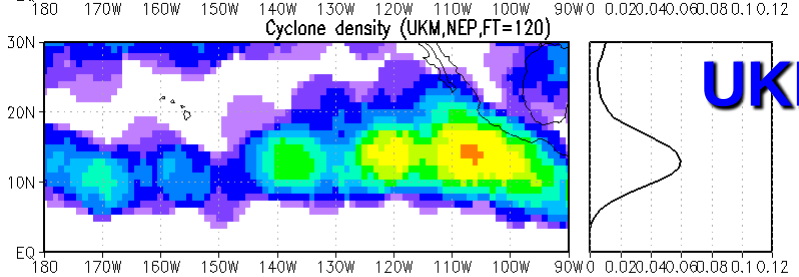
JMA



NCEP

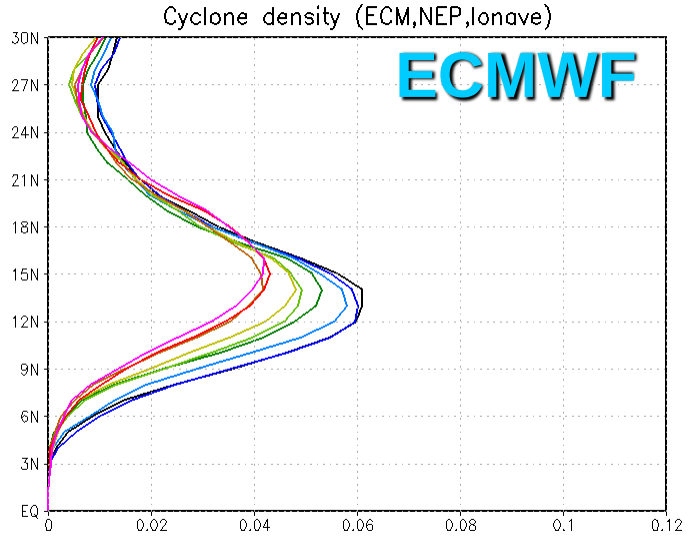


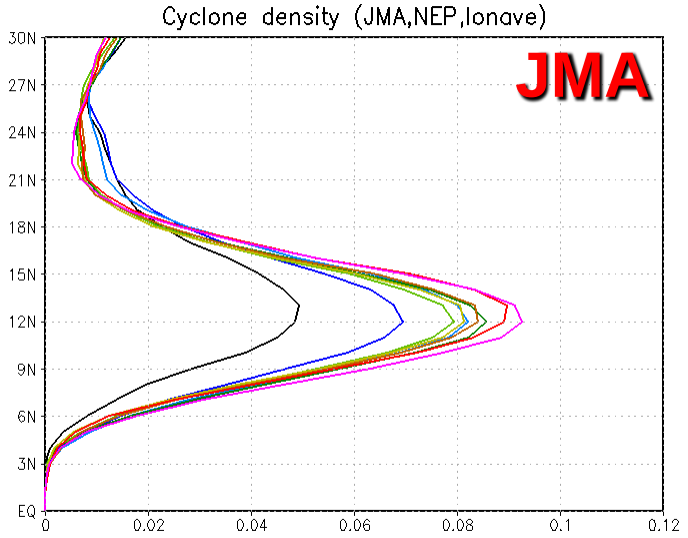
NRL

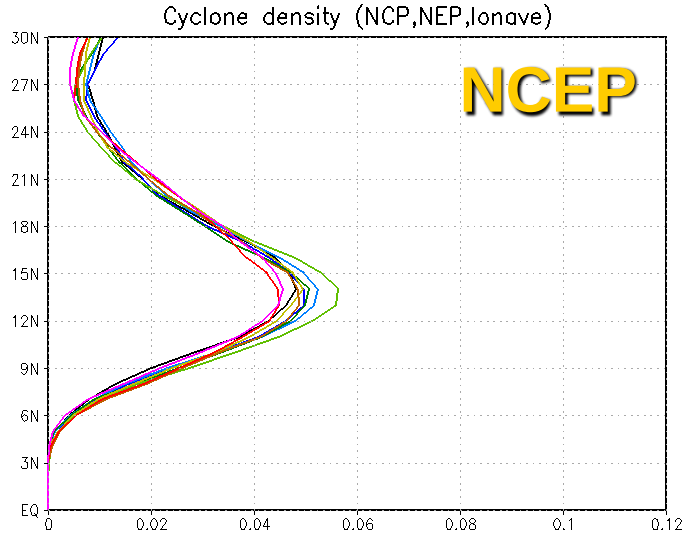


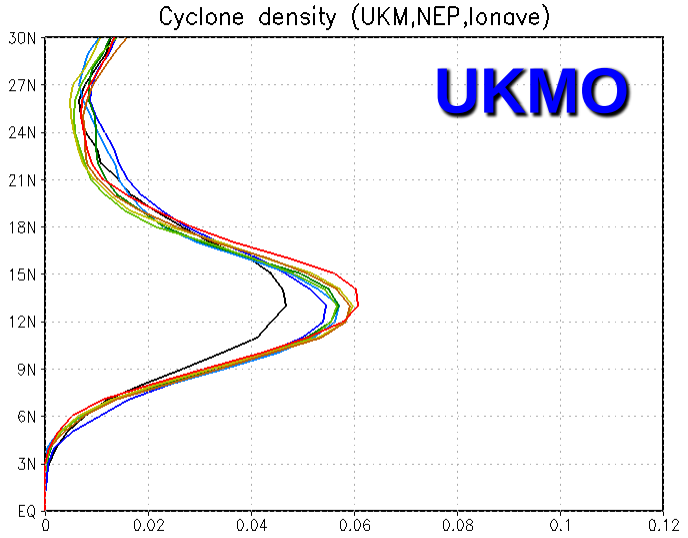
UKMO

Comparison of 4 NWP centers (ENP)

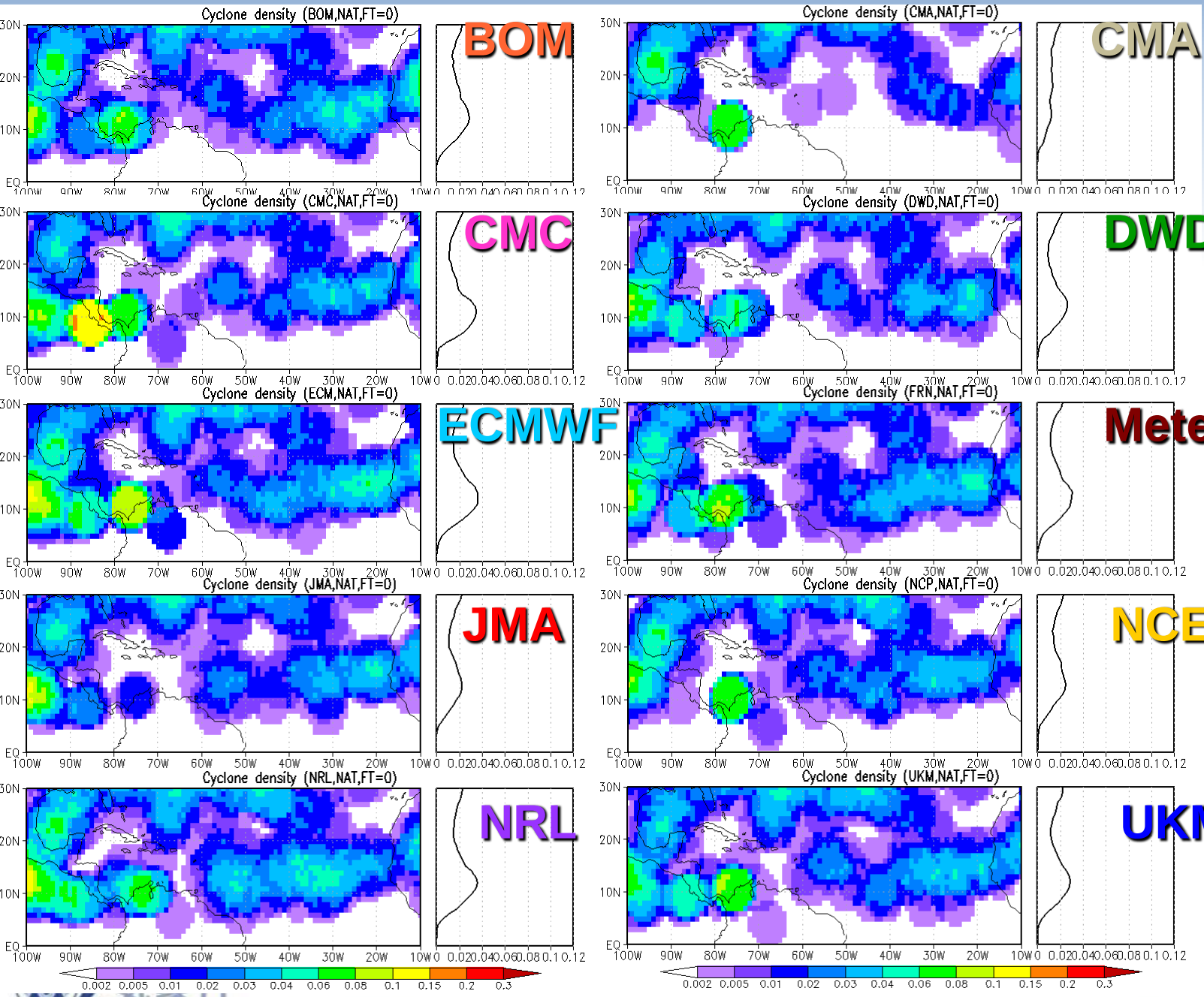


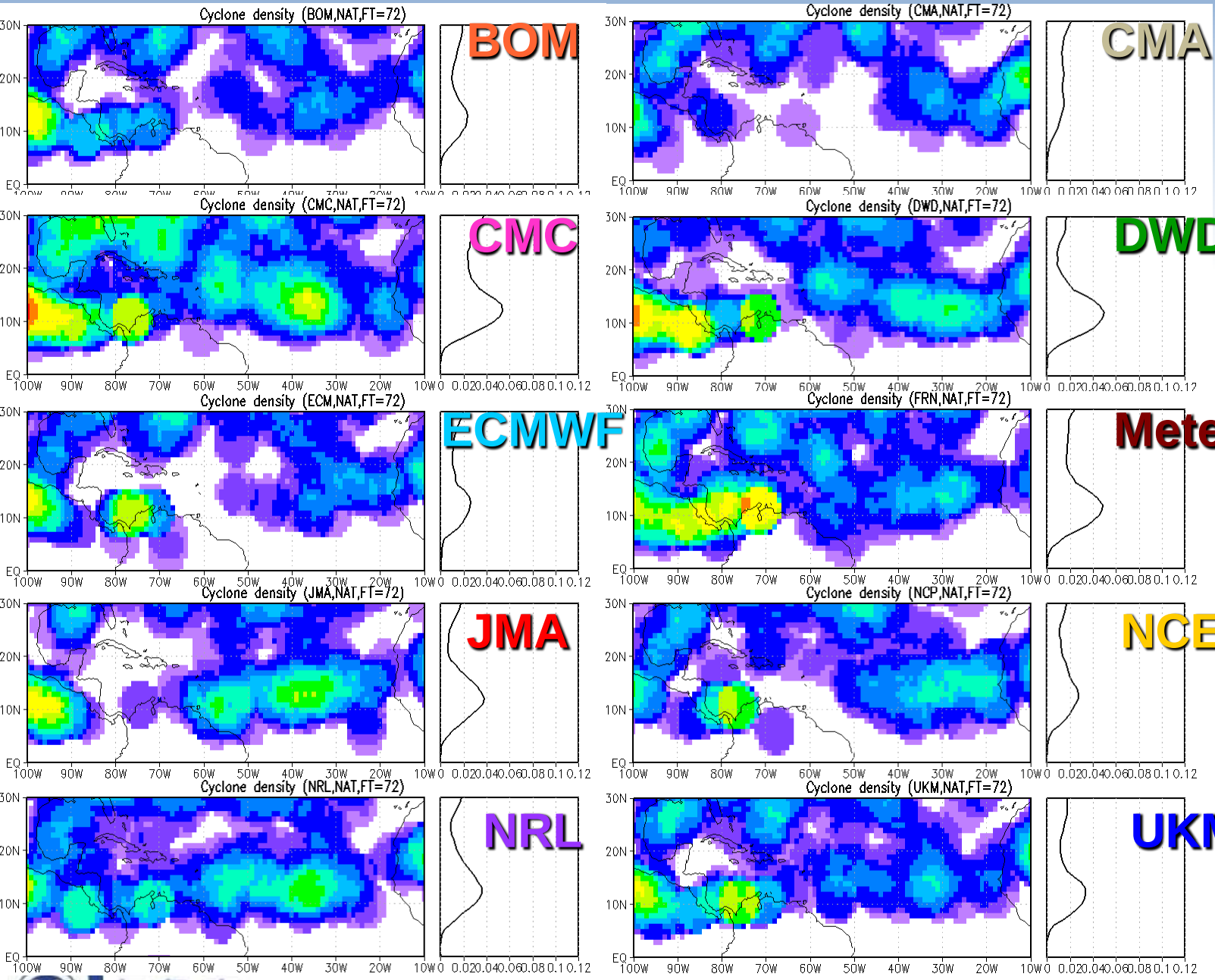


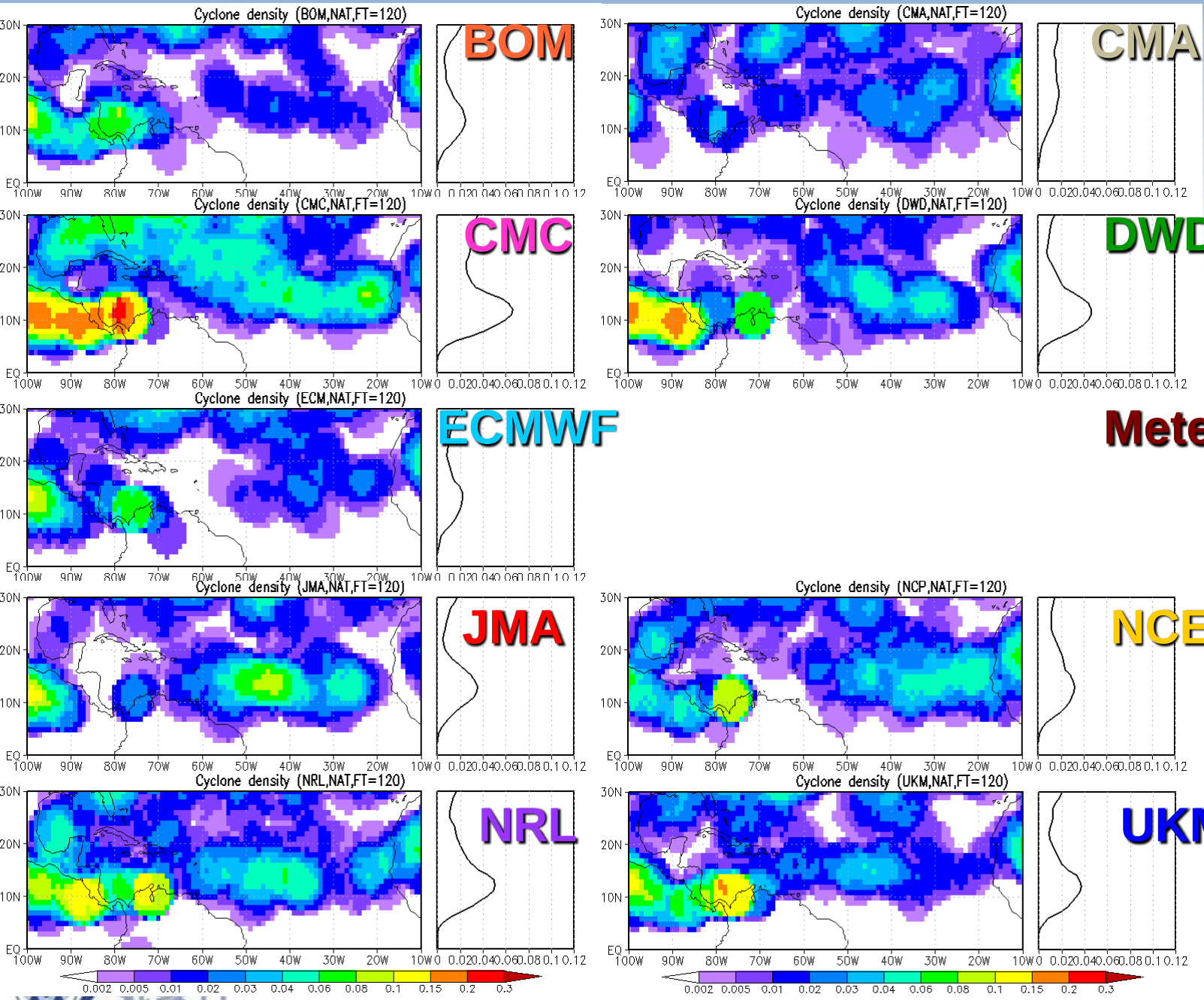




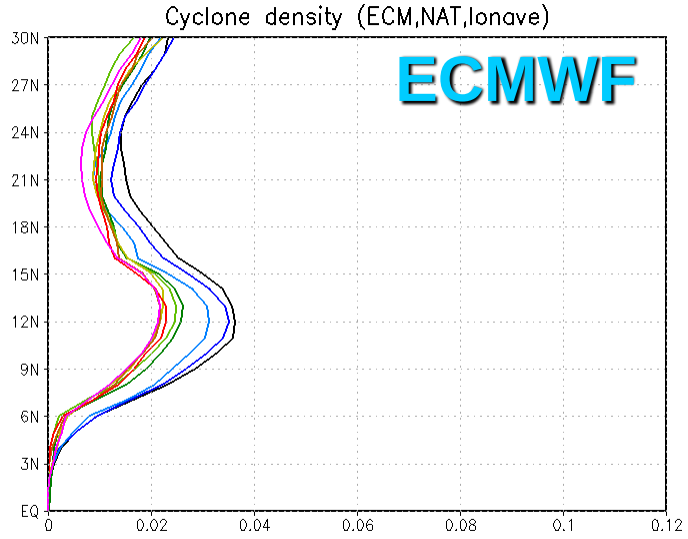
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

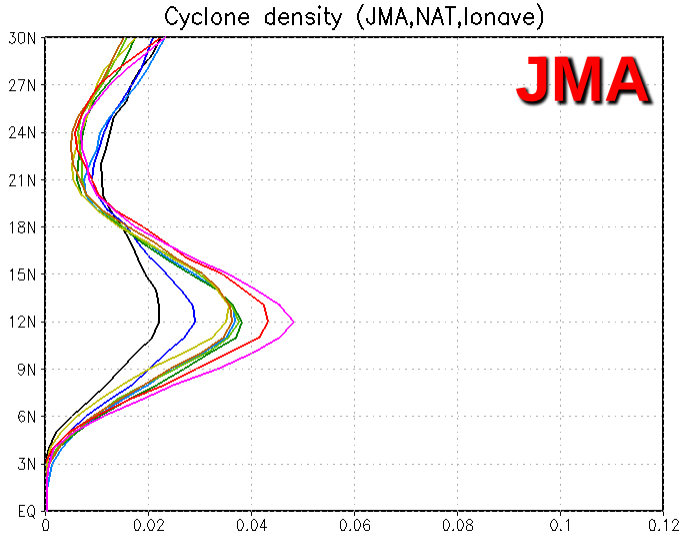

Cyclone density (BOM,NAT,FT=0)
BOM
Cyclone density (CMA,NAT,FT=0)
CMA
NAT domain FT=0
Cyclone density (CMC,NAT,FT=0)
CMC
Cyclone density (DWD,NAT,FT=0)
DWD
Cyclone density (ECM,NAT,FT=0)
ECMWF
Cyclone density (FRN,NAT,FT=0)
Meteo France
Cyclone density (JMA,NAT,FT=0)
JMA
Cyclone density (NCP,NAT,FT=0)
NCEP
Cyclone density (NRL,NAT,FT=0)
NRL
Cyclone density (UKM,NAT,FT=0)
UKMO
30N
20N
10N
EQ
100W 90W 80W 70W 60W 50W 40W 30W 20W 10W
0 0.02 0.04 0.06 0.08 0.1 0.12
0.002 0.005 0.01 0.02 0.03 0.04 0.06 0.08 0.1 0.15 0.2 0.3

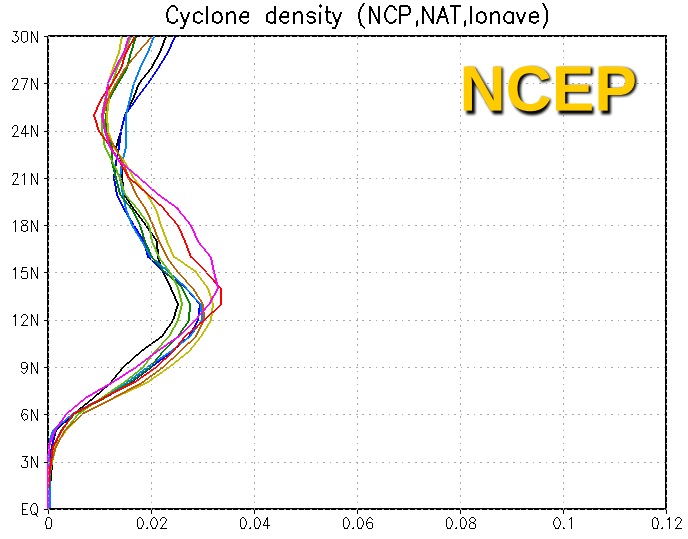

Cyclone density (BOM,NAT,FT=72)
BOM
Cyclone density (CMA,NAT,FT=72)
CMA
NAT domain FT=72
Cyclone density (CMC,NAT,FT=72)
CMC
Cyclone density (DWD,NAT,FT=72)
DWD
Cyclone density (ECM,NAT,FT=72)
ECMWF
Cyclone density (FRN,NAT,FT=72)
Meteo France
Cyclone density (JMA,NAT,FT=72)
JMA
Cyclone density (NCP,NAT,FT=72)
NCEP
Cyclone density (NRL,NAT,FT=72)
NRL
Cyclone density (UKM,NAT,FT=72)
UKMO

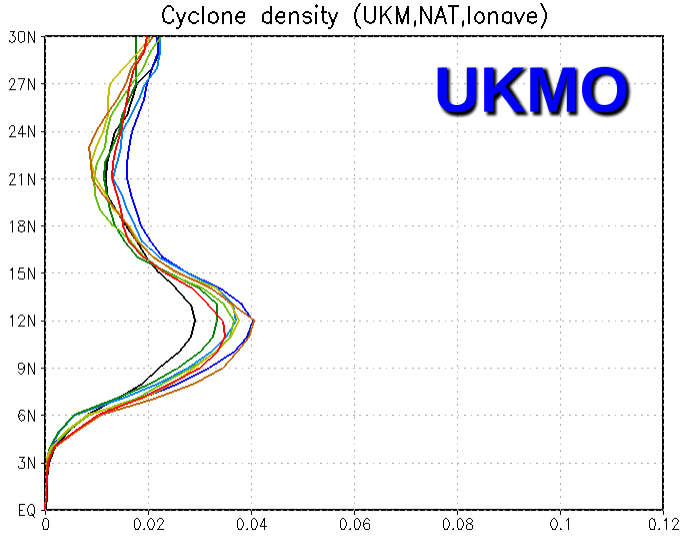

Cyclone density (BOM,NAT,FT=120)
BOM
Cyclone density (CMA,NAT,FT=120)
CMA
NAT domain FT=120
Cyclone density (CMC,NAT,FT=120)
CMC
Cyclone density (DWD,NAT,FT=120)
DWD
Cyclone density (ECM,NAT,FT=120)
ECMWF
Meteo France
Cyclone density (JMA,NAT,FT=120)
JMA
Cyclone density (NCP,NAT,FT=120)
NCEP
Cyclone density (NRL,NAT,FT=120)
NRL
Cyclone density (UKM,NAT,FT=120)
UKMO
0.002 0.005 0.01 0.02 0.03 0.04 0.06 0.08 0.1 0.15 0.2 0.3

Comparison of 4 NWP centers (NAT)

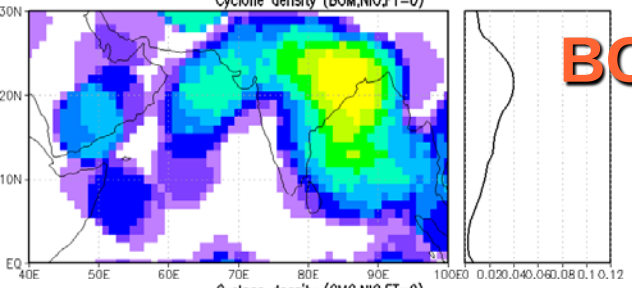




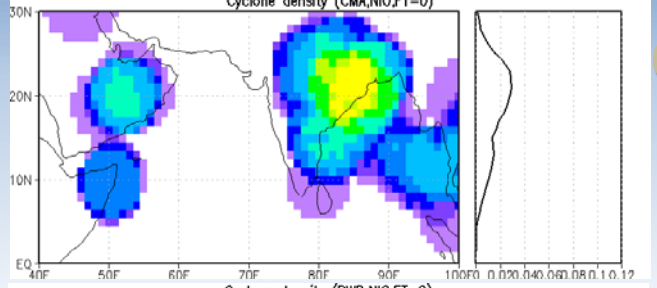




FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

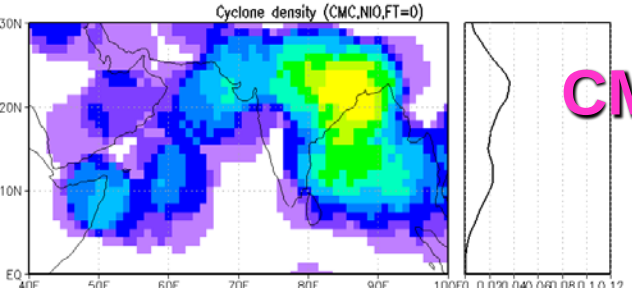


BOM

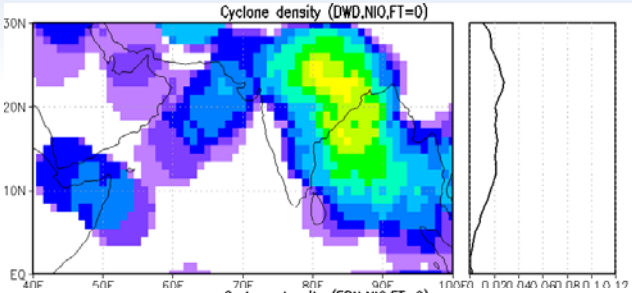


CMA

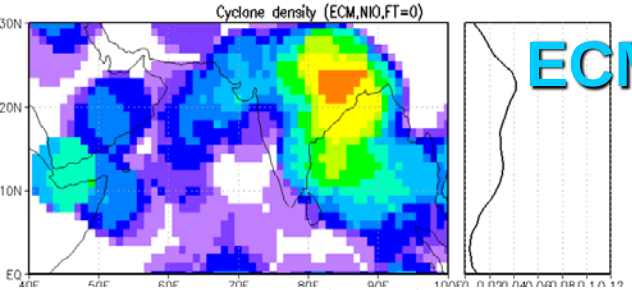
NIO domain FT=0



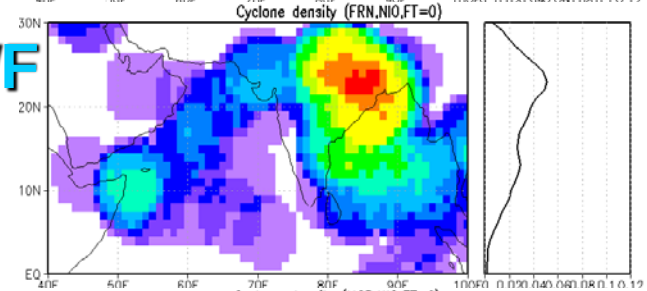
CMC



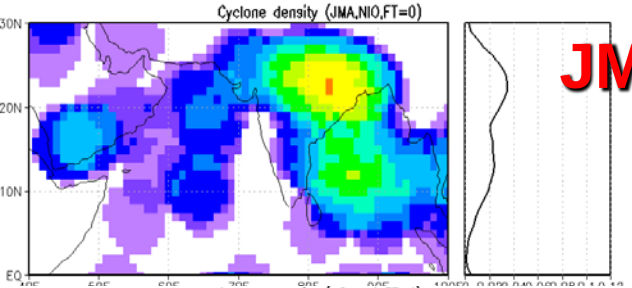
DWD



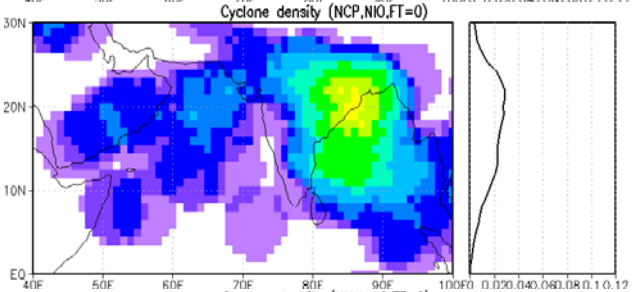
ECMWF



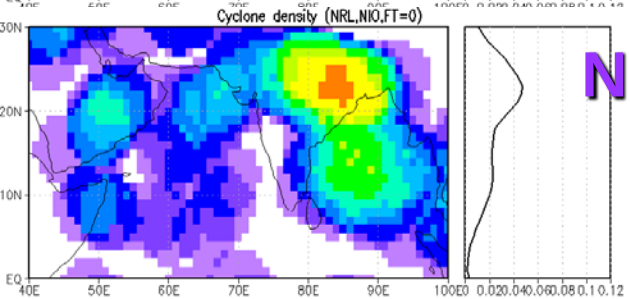
Meteo France



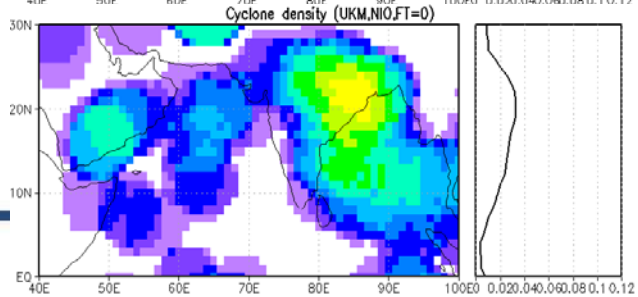
JMA



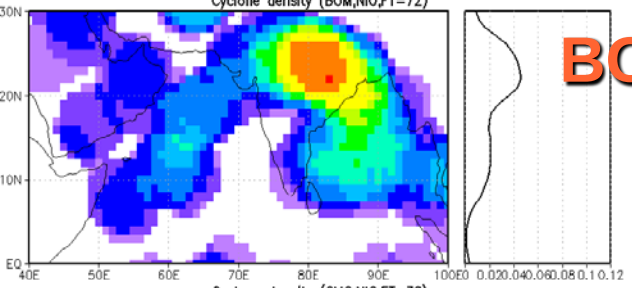
NCEP



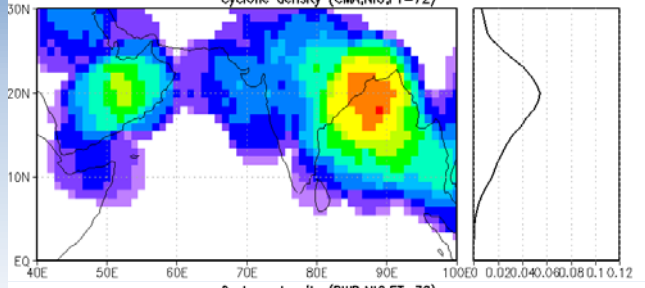
NRL



UKMO

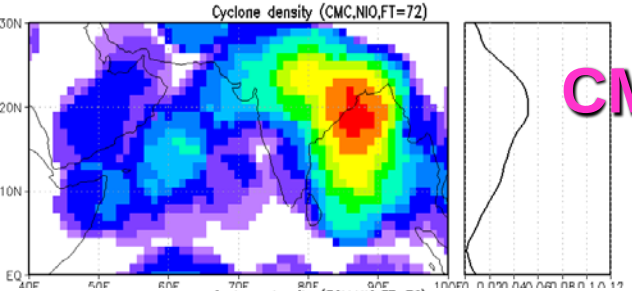


BOM

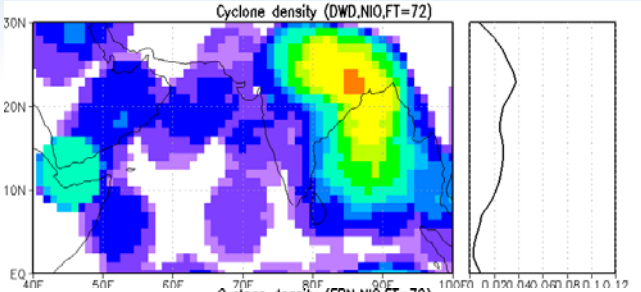


CMA

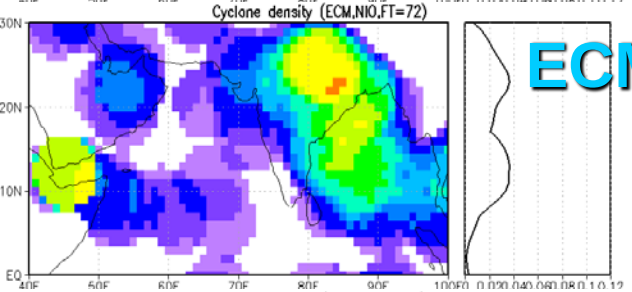
NIO domain FT=72



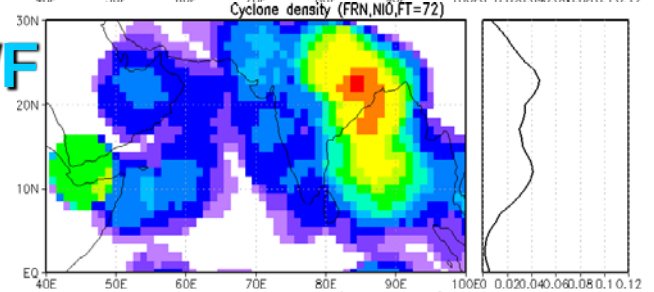
CMC



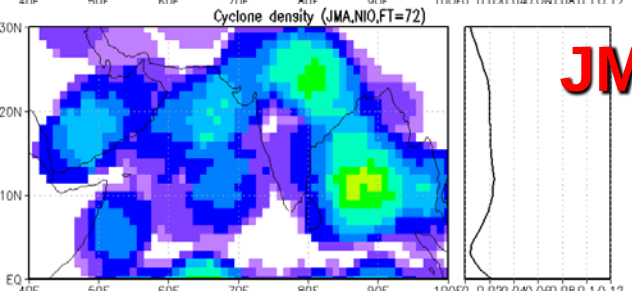
DWD



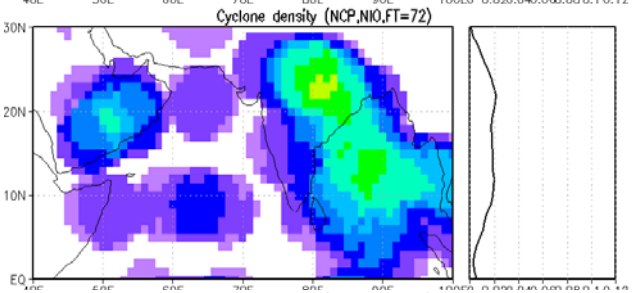
ECMWF



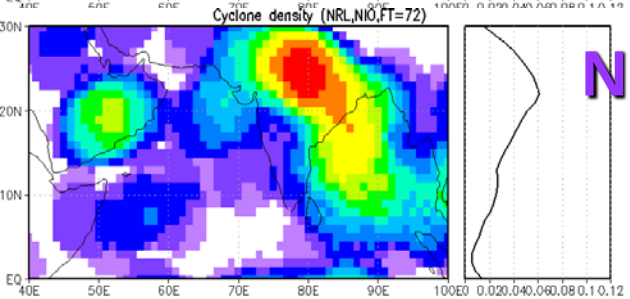
Meteo France



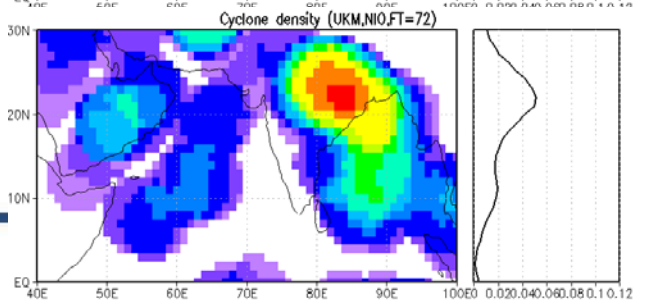
JMA



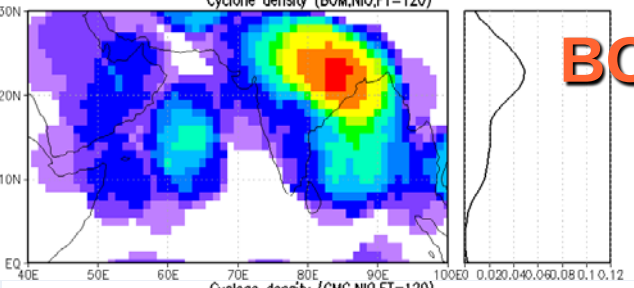
NCEP



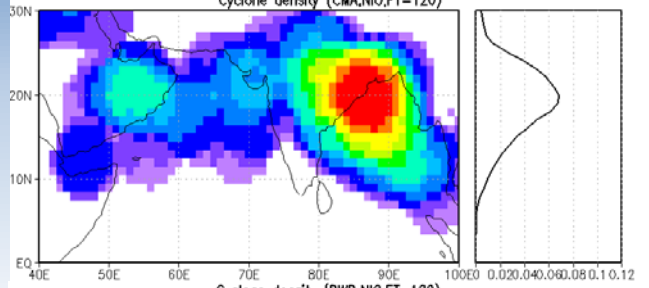
NRL



UKMO

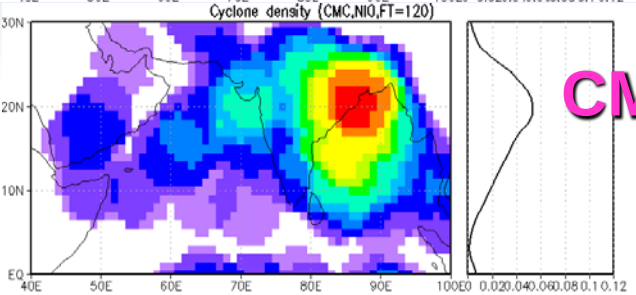


BOM

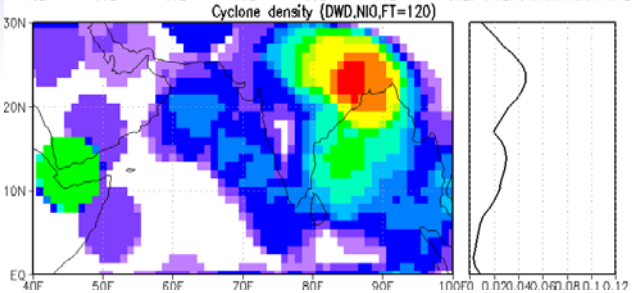


CMA

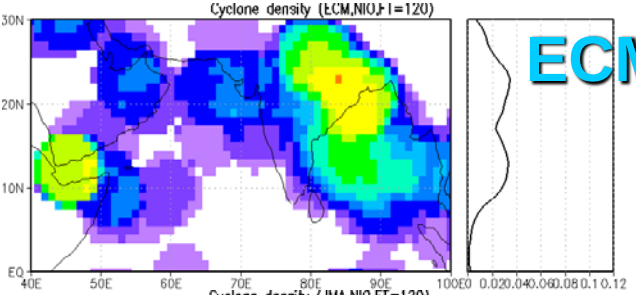
NIO domain FT=120



CMC

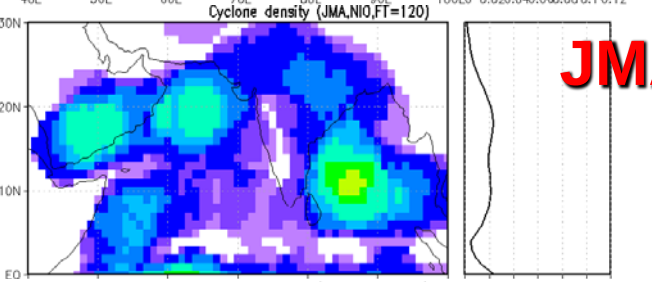


DWD

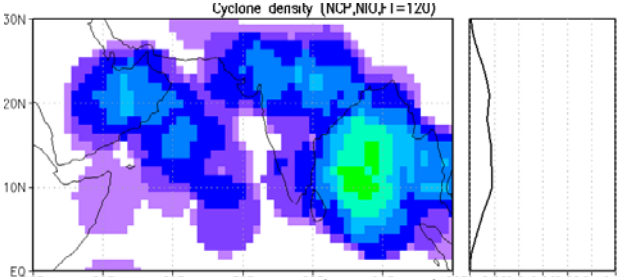


ECMWF

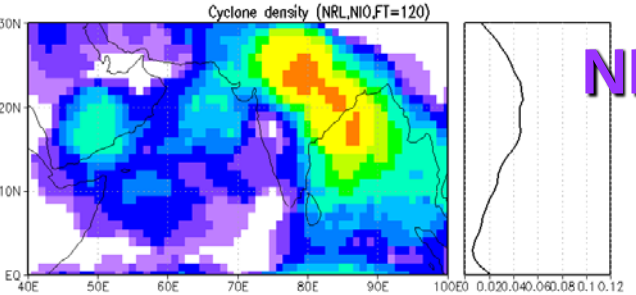
Meteo France



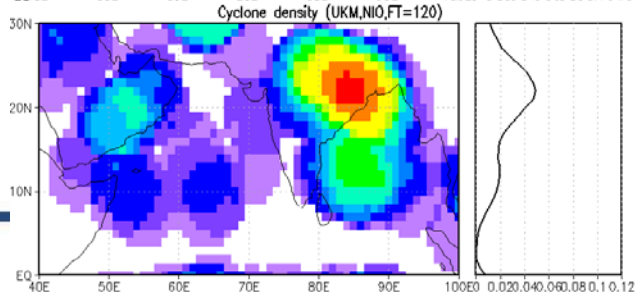
JMA



NCEP

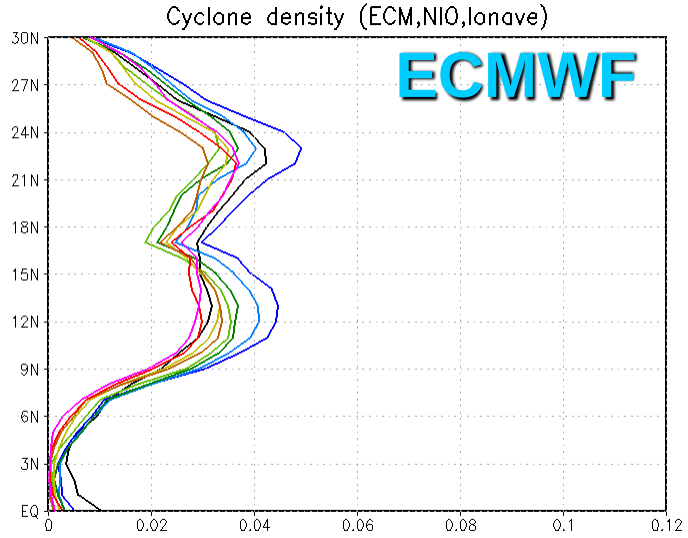


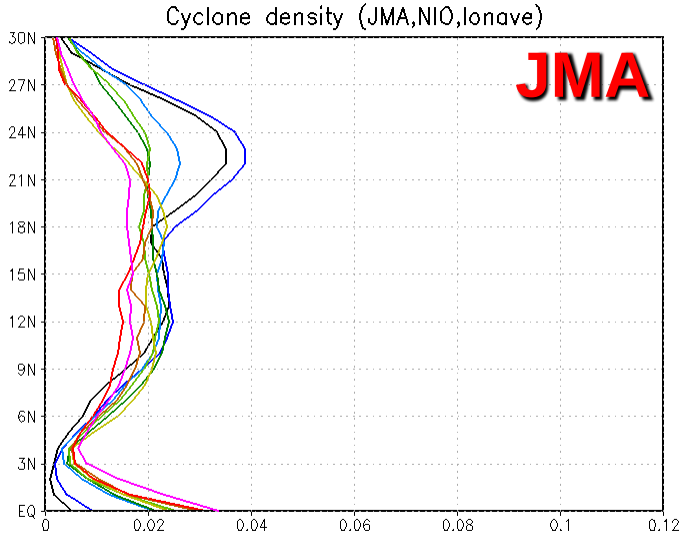
NRL

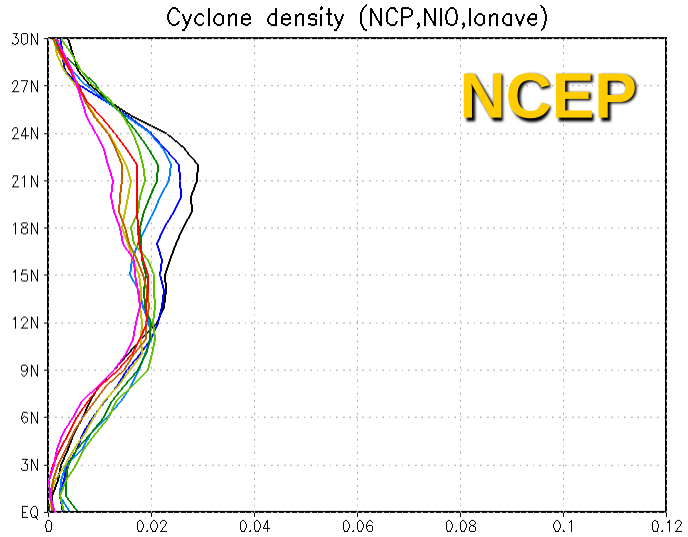


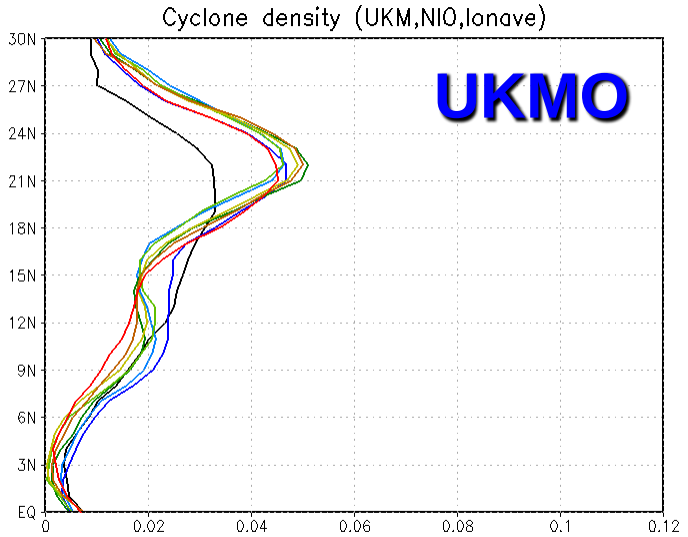
UKMO

Comparison of 4 NWP centers (NIO)

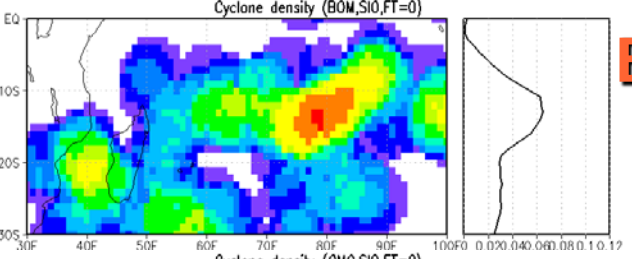




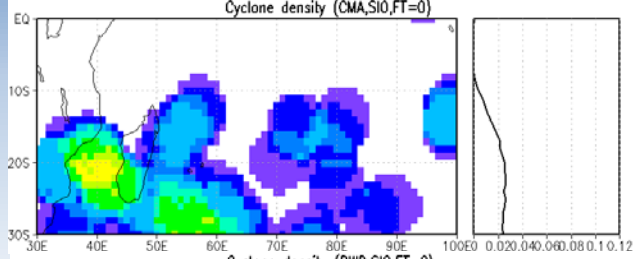




FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

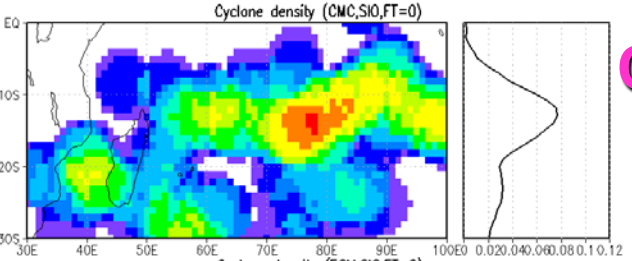


BOM

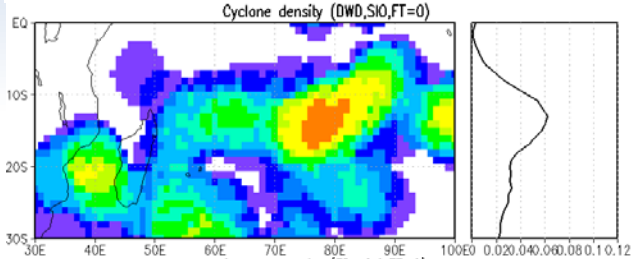


CMA

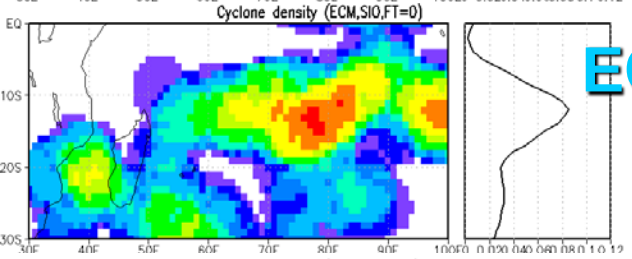
SIO domain FT=0



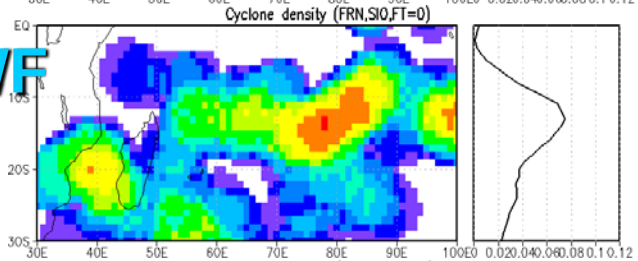
CMC



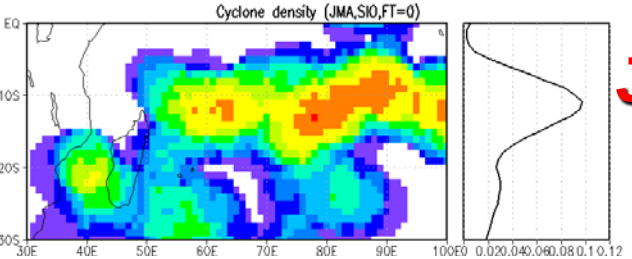
DWD



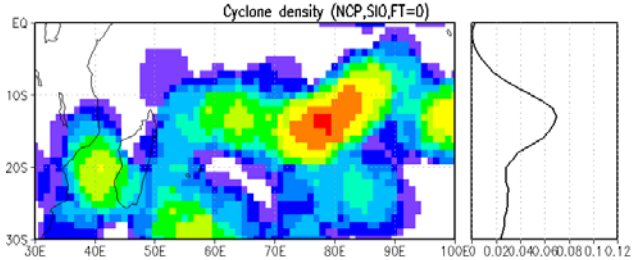
ECMWF



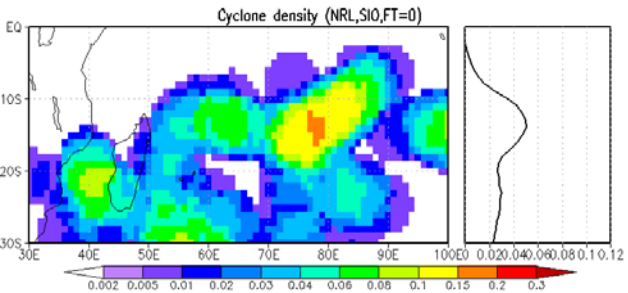
Meteo France



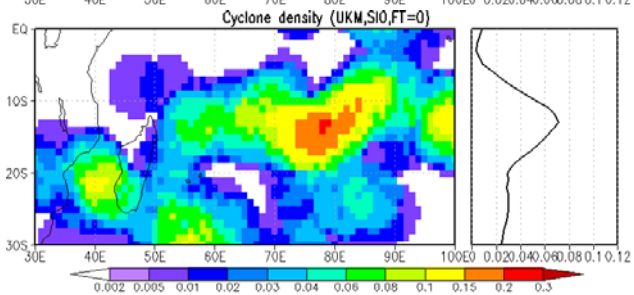
JMA



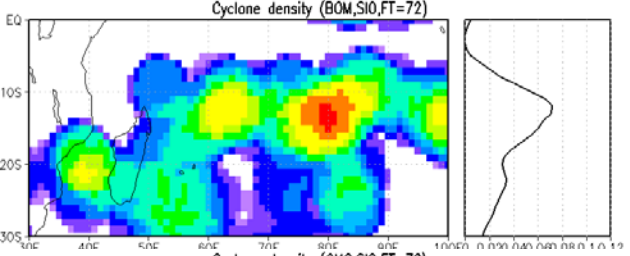
NCEP



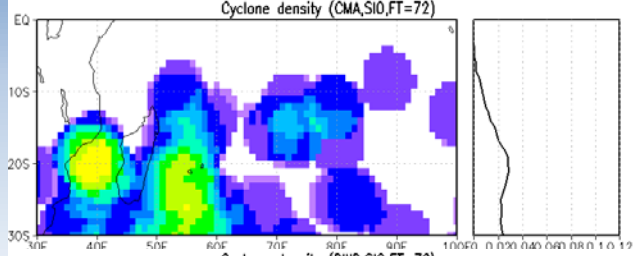
NRL



UKMO

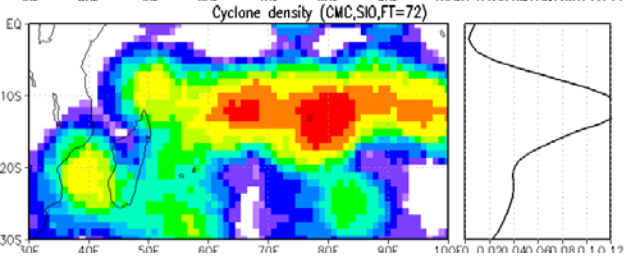


BOM

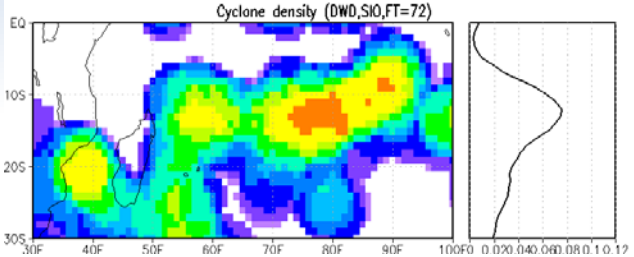


CMA

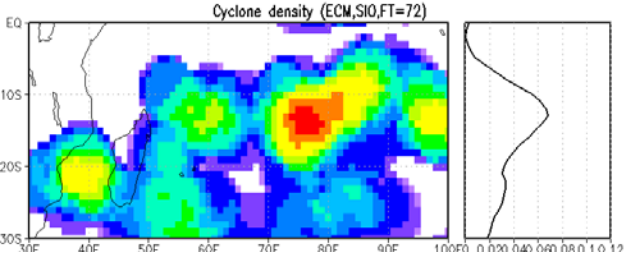
SIO domain FT=72



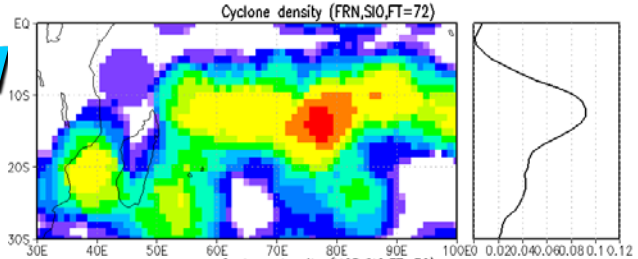
CMC



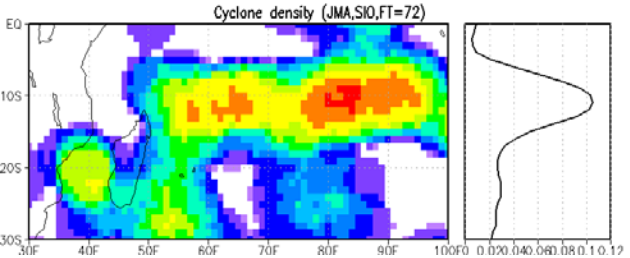
DWD



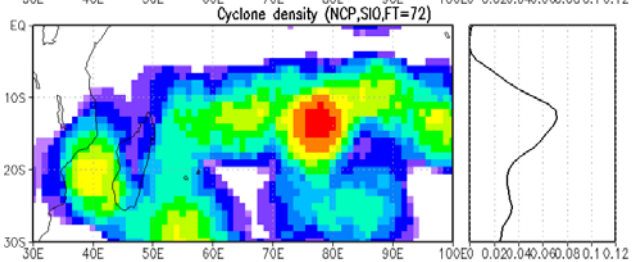
CMW



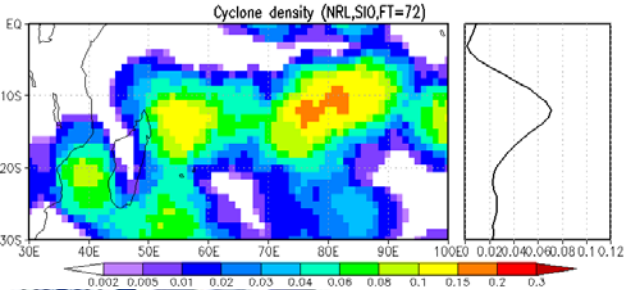
Meteo France



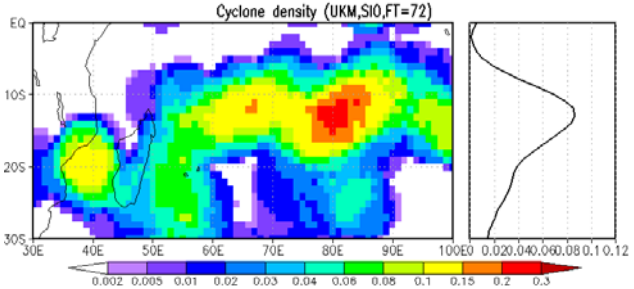
JMA



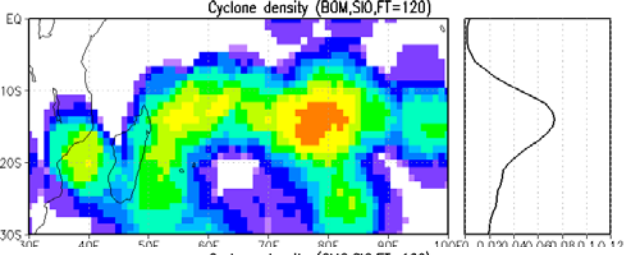
NCEP



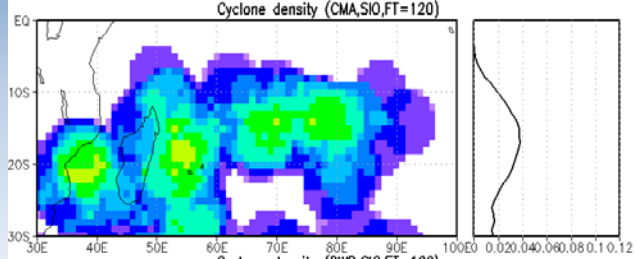
NRL



UKMO

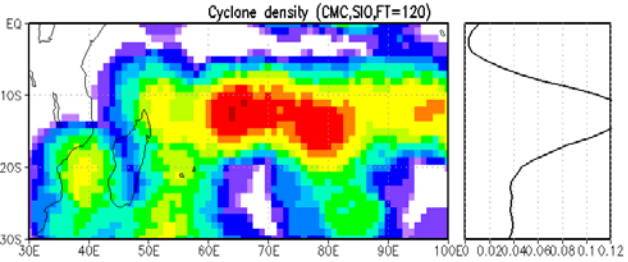


BOM

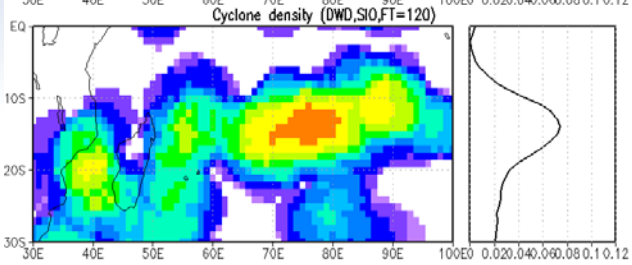


CMA

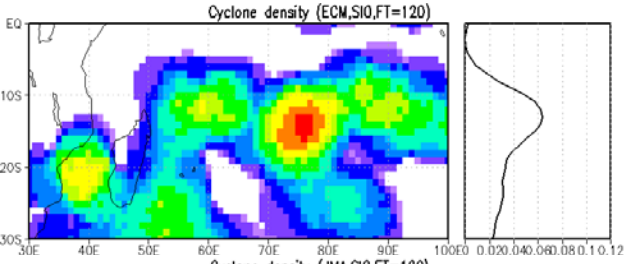
SIO domain FT=120



CMC

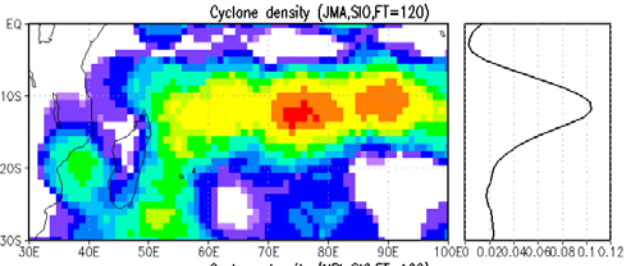


DWD

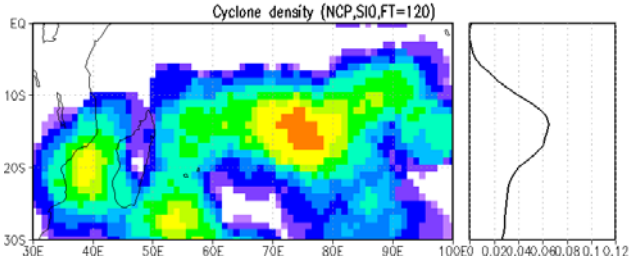


CMWF

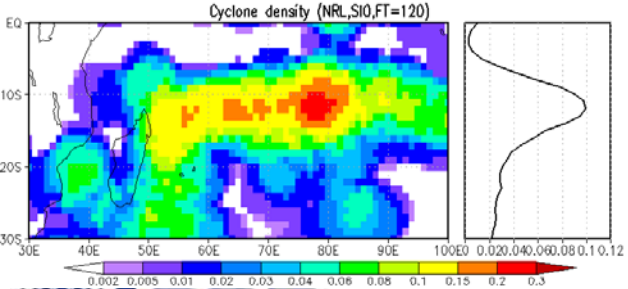
Meteo France



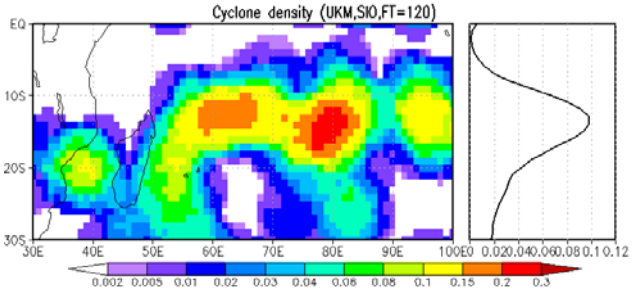
JMA



NCEP

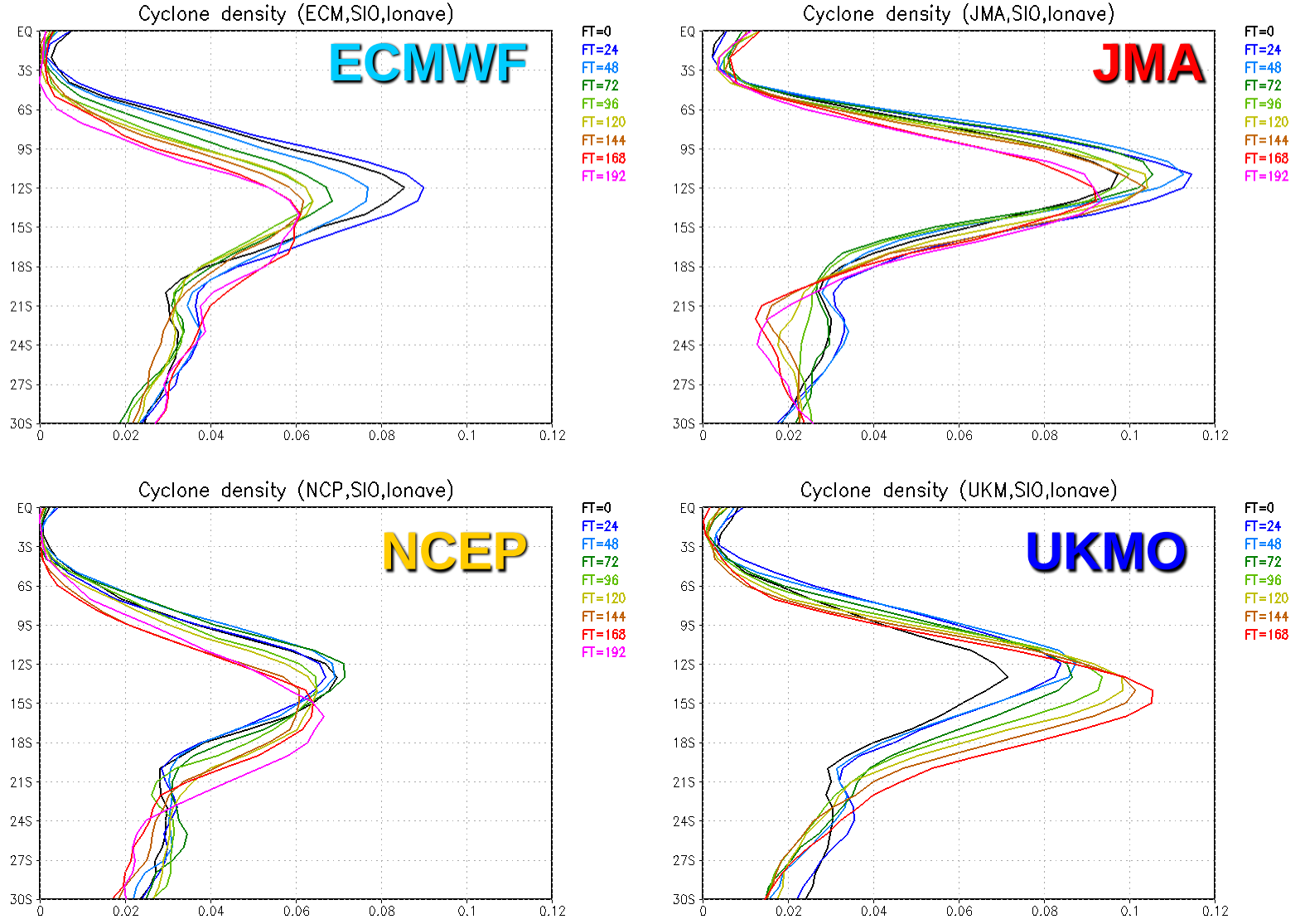


NRL

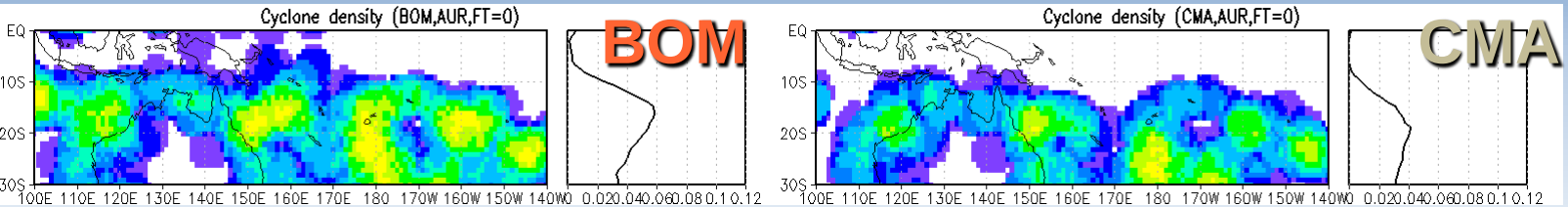


UKMO

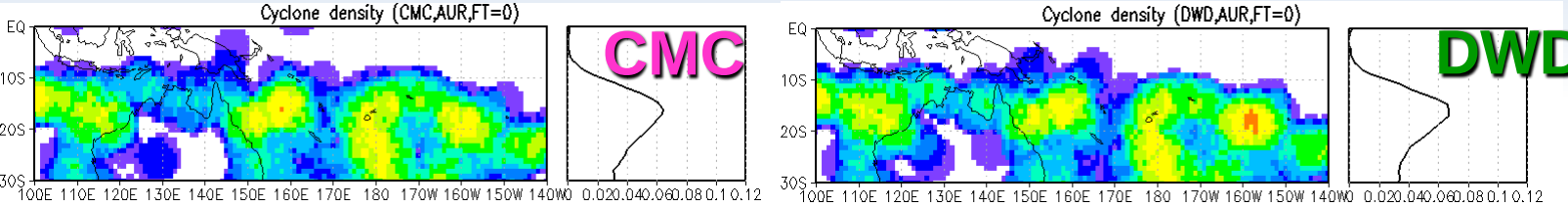
Comparison of 4 NWP centers (SIO)

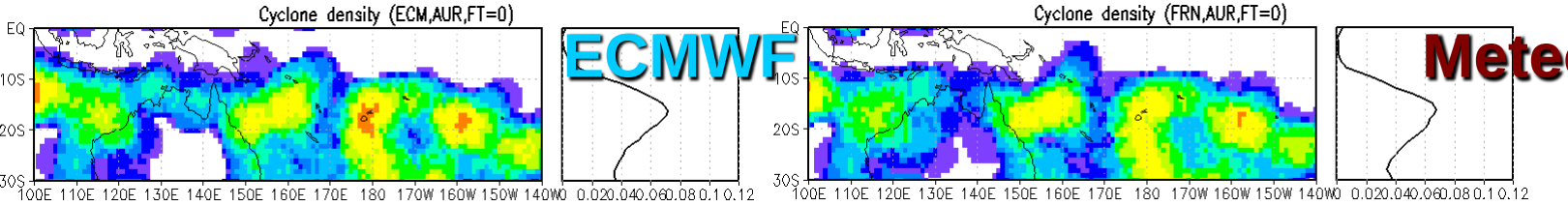


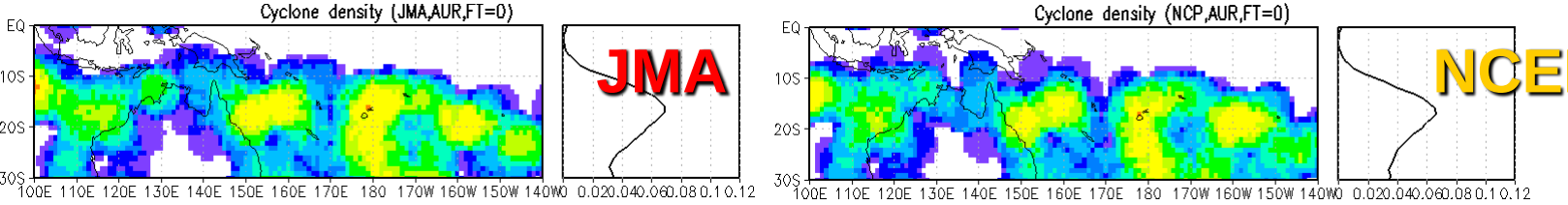
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

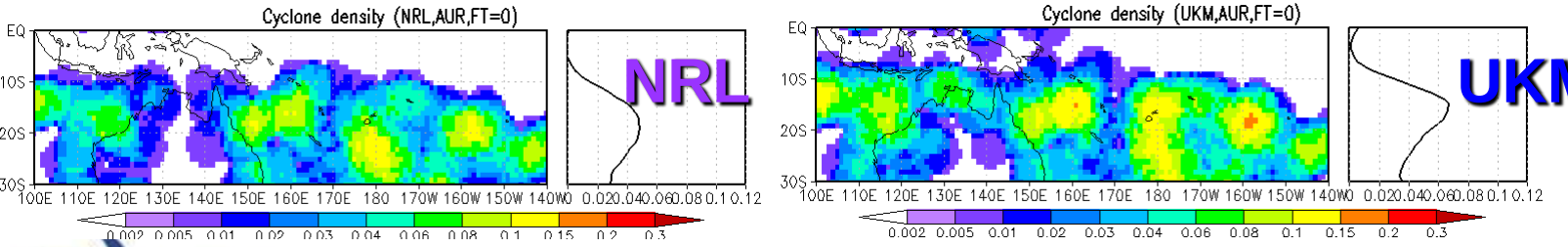


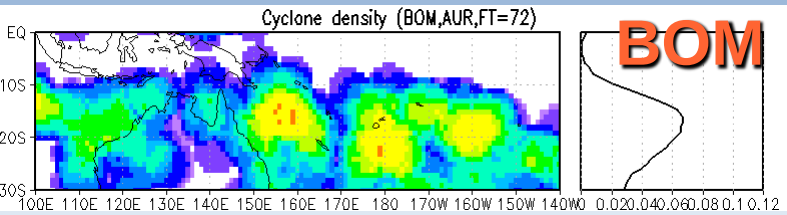
AUR domain FT=0



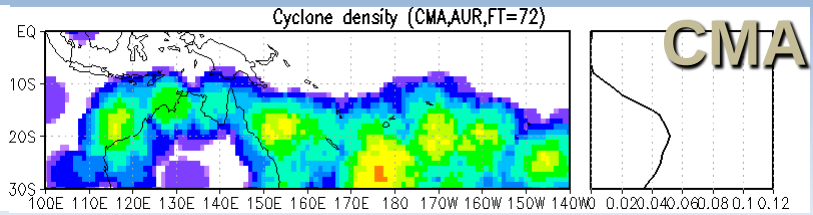






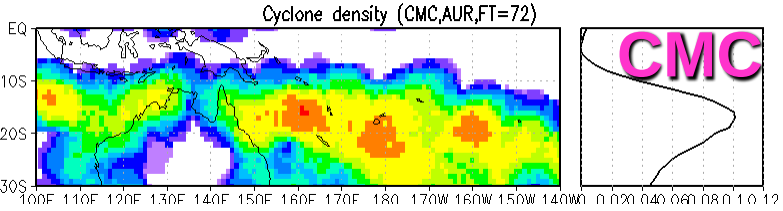


BOM

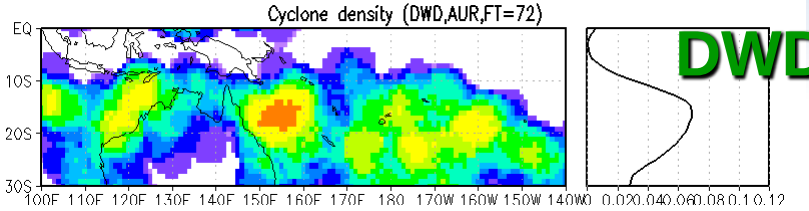


CMA

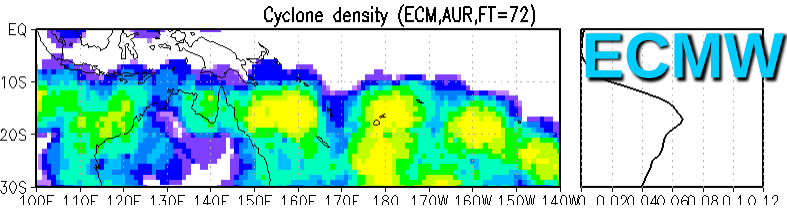
AUR domain FT=72



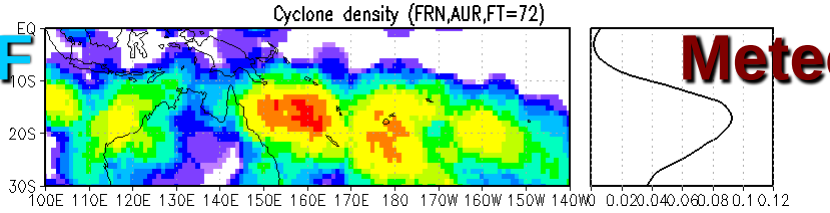
CMC



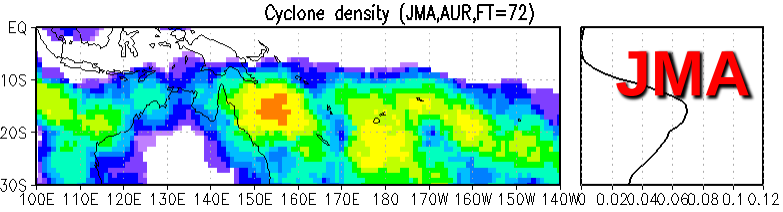
DWD



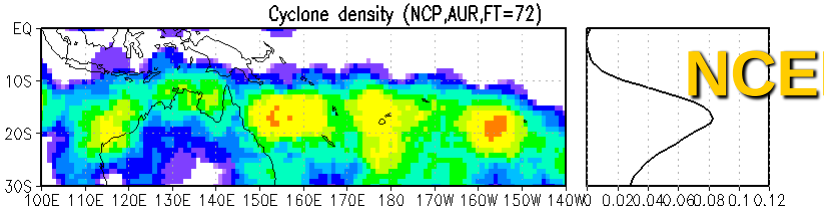
ECMWF



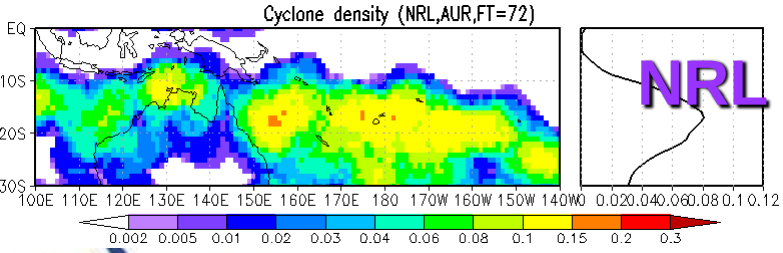
Meteo France



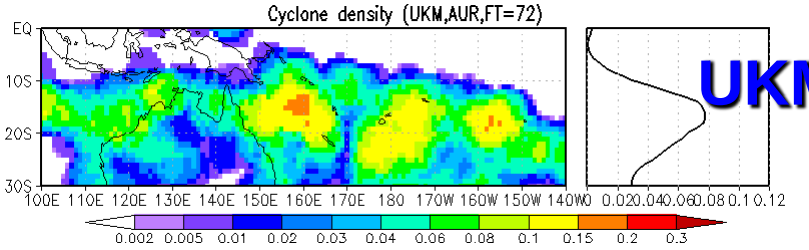
JMA



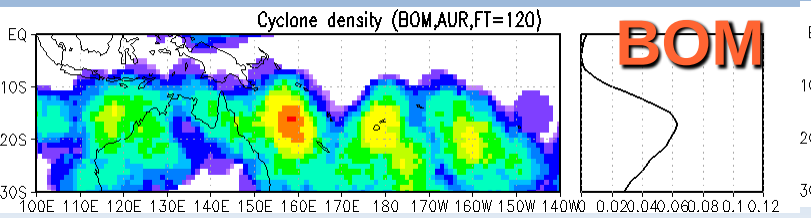
NCEP



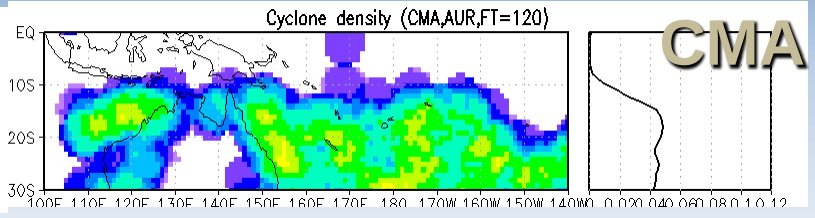
NRL



UKMO

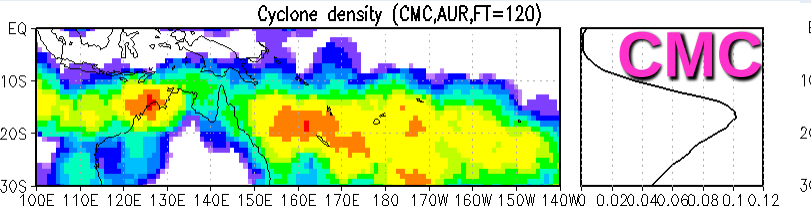


BOM

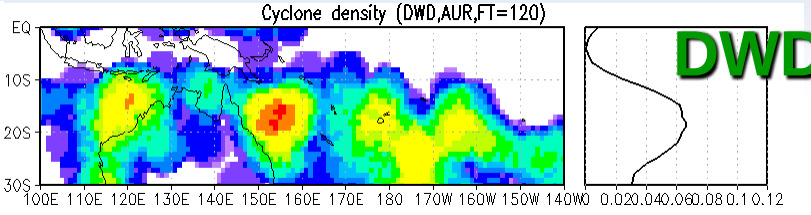


CMA

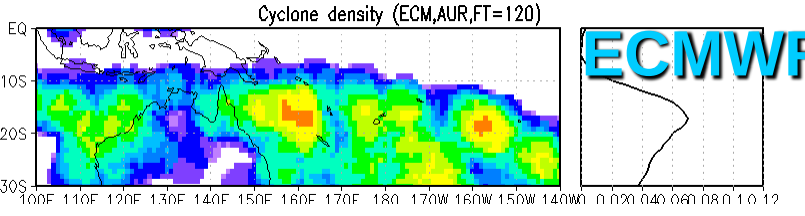
AUR domain FT=120



CMC

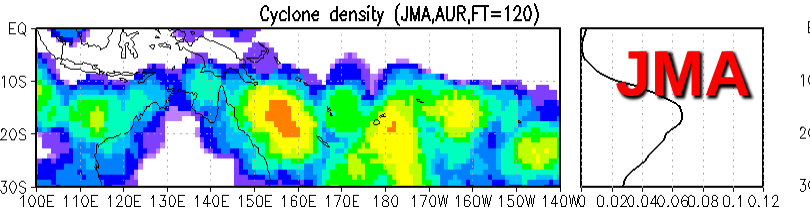


DWD

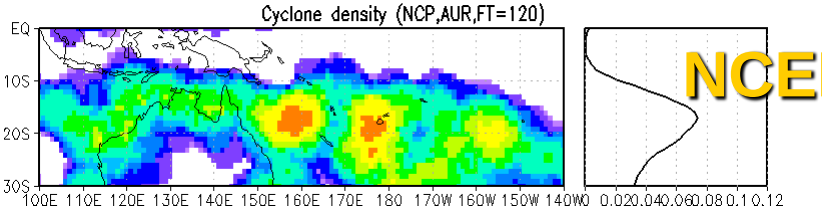


ECMWF

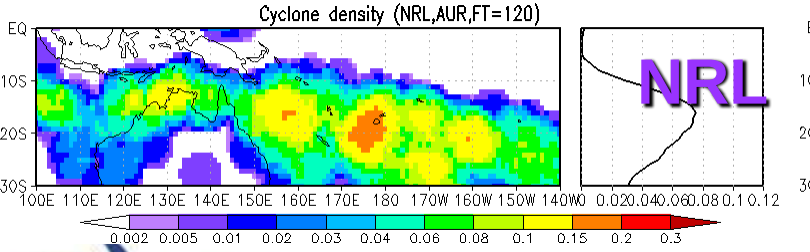
Meteo France



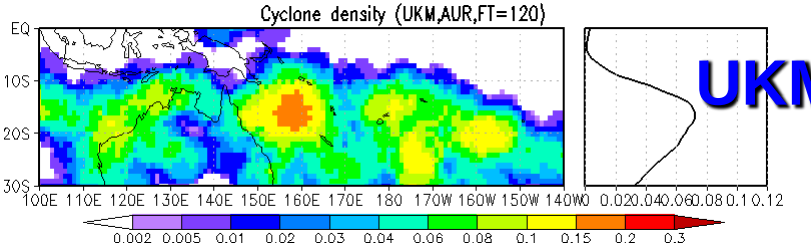
JMA



NCEP

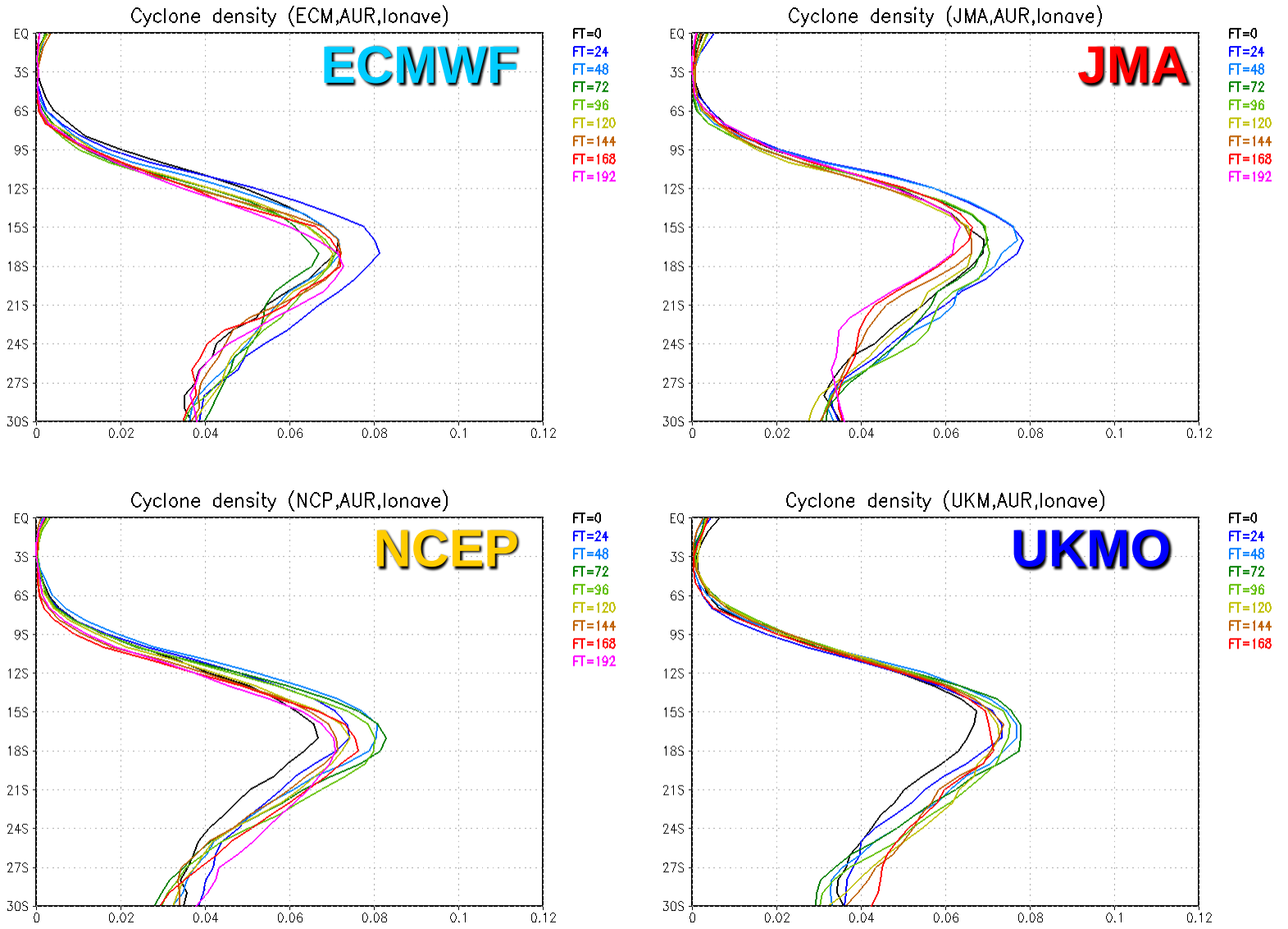


NRL

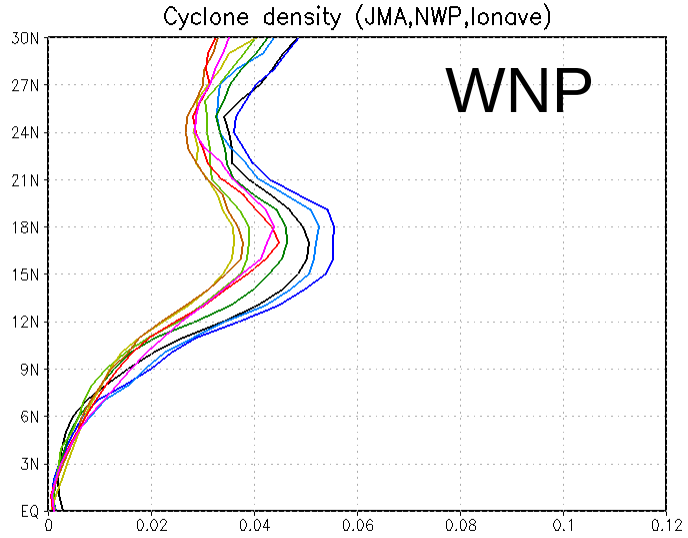


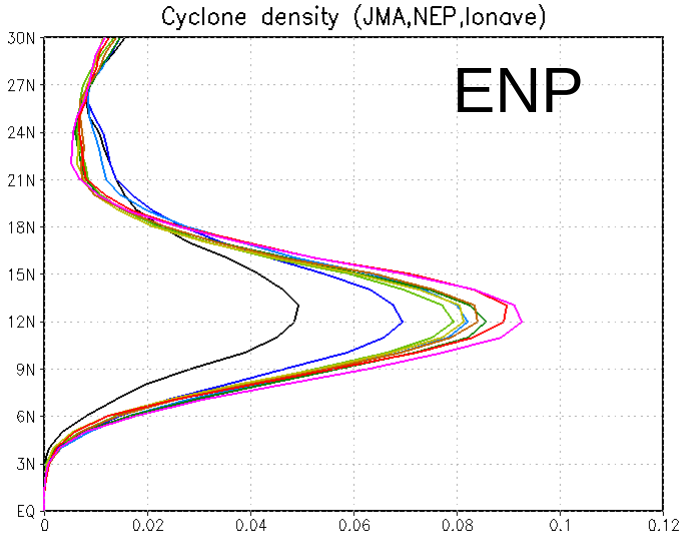
UKMO

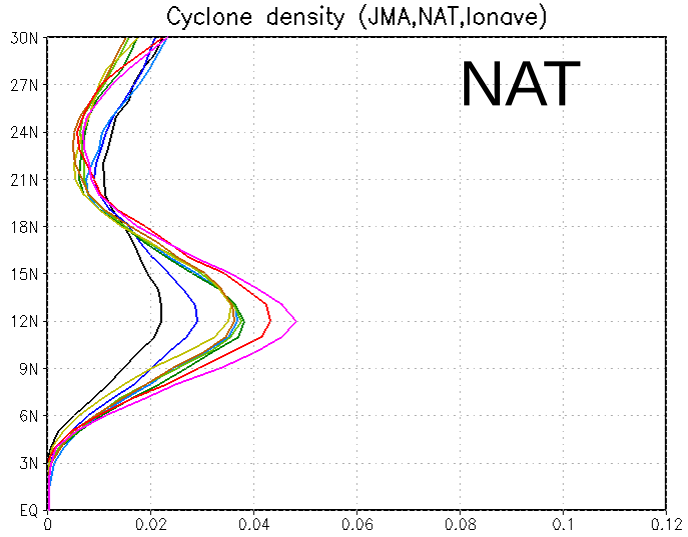
Comparison of 4 NWP centers (AUR)

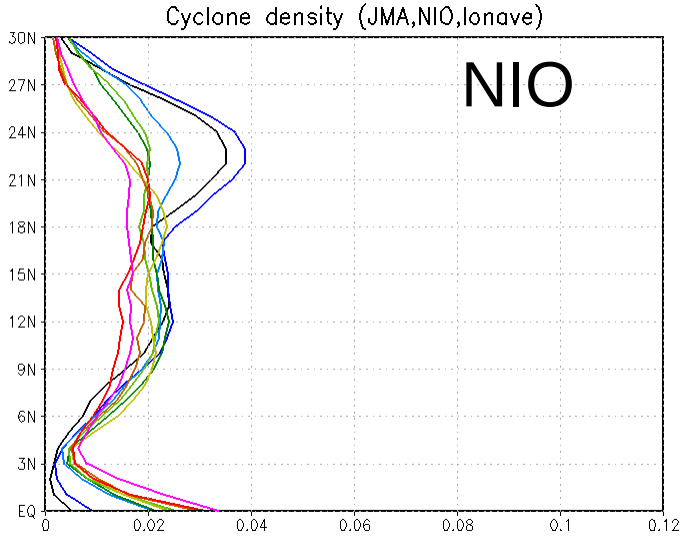


JMA (2013)

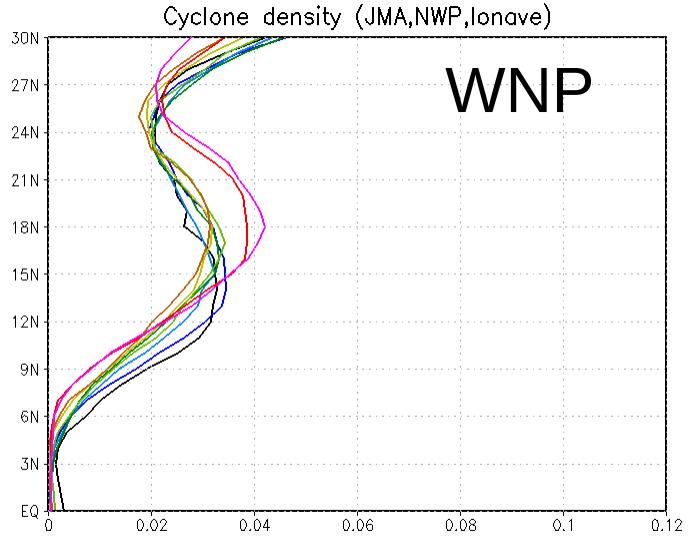

Cyclone density (JMA,NWP,Ionave)
WNP
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

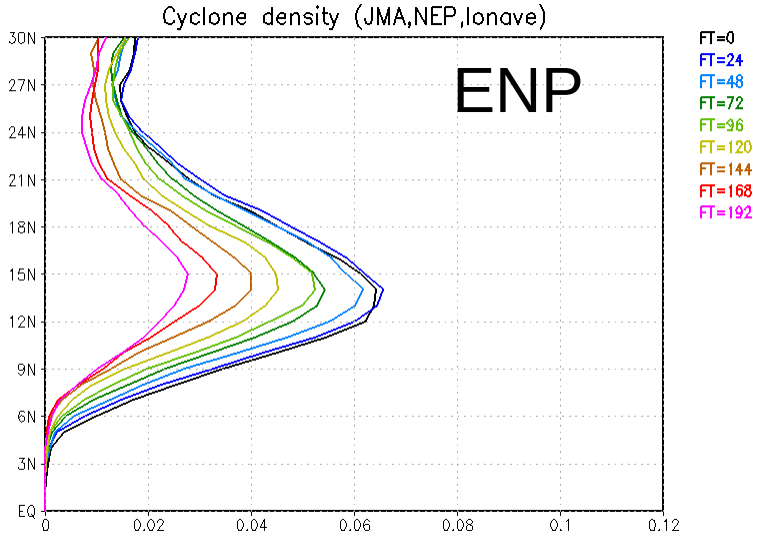

Cyclone density (JMA,NEP,Ionave)
ENP
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

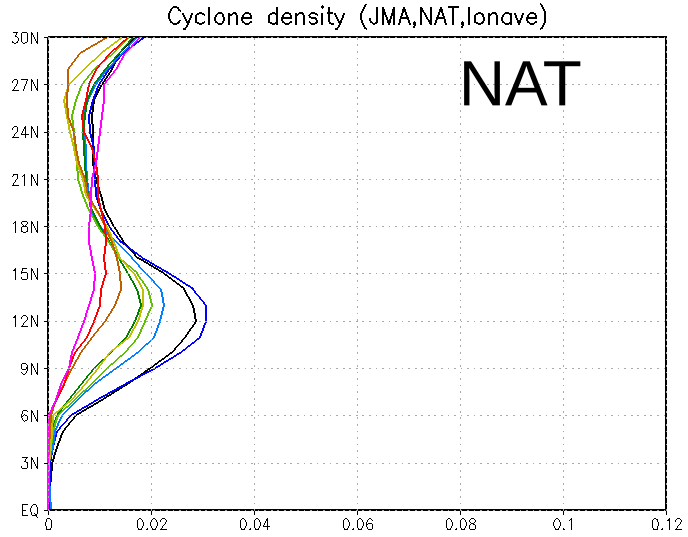

Cyclone density (JMA,NAT,Ionave)
NAT
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

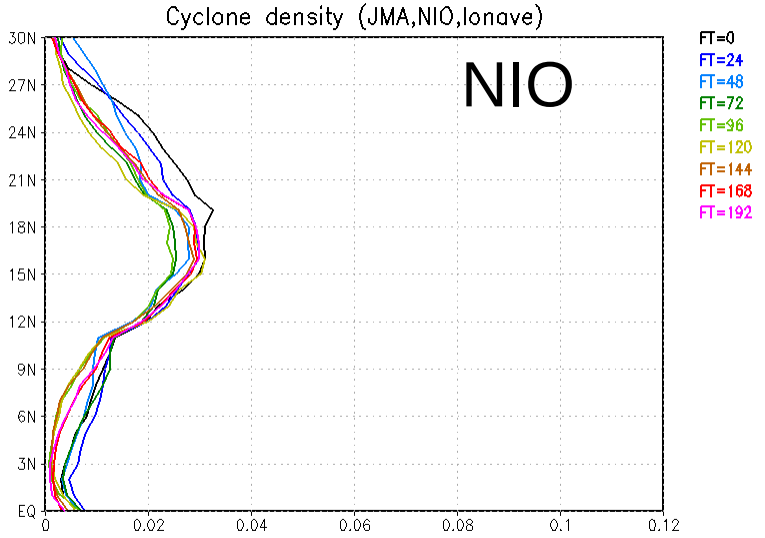

Cyclone density (JMA,NIO,Ionave)
NIO
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

JMA (2014)

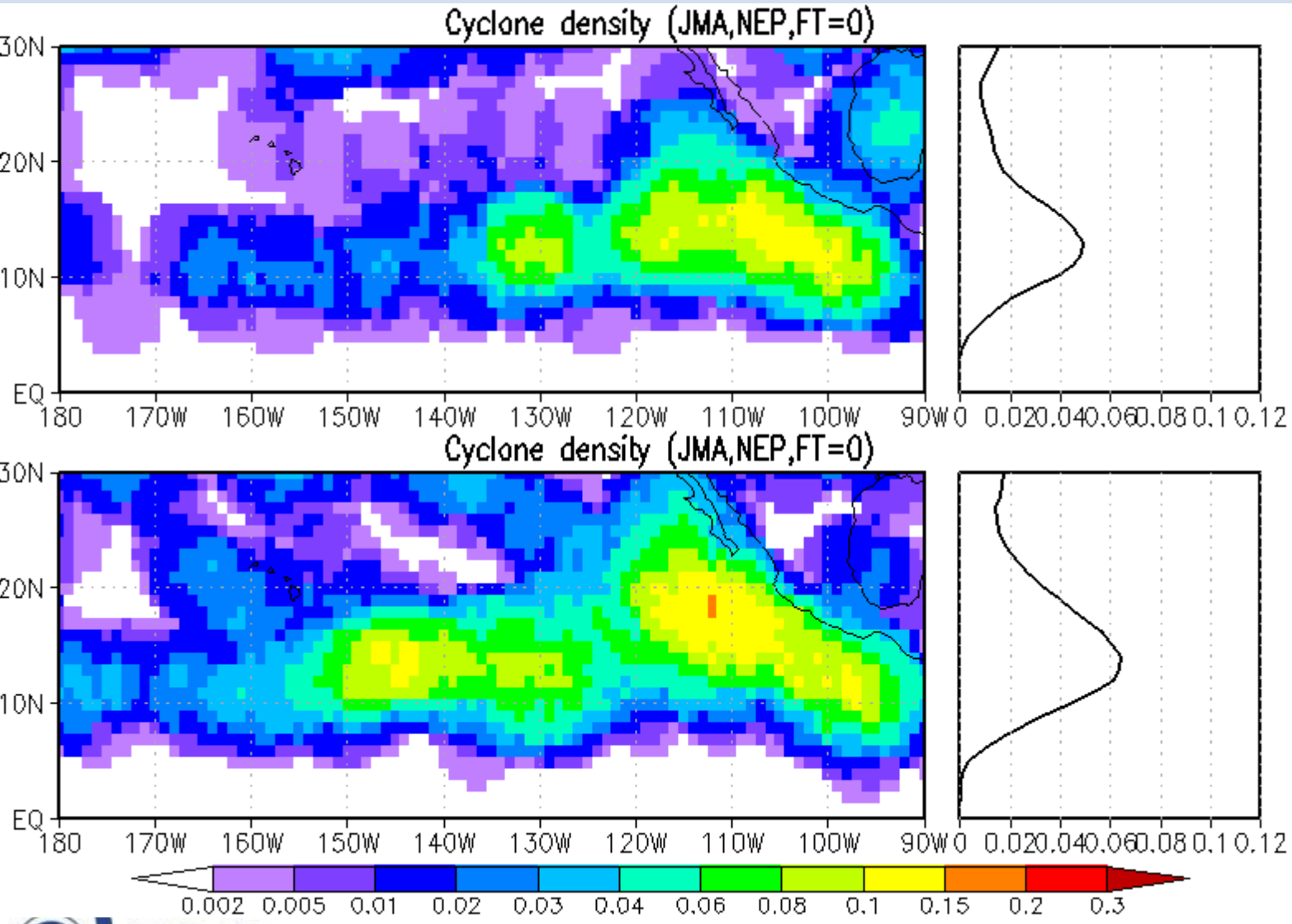

Cyclone density (JMA,NWP,Ionave)
WNP
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192


Cyclone density (JMA,NEP,Ionave)
ENP
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192


Cyclone density (JMA,NAT,Ionave)
NAT
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192


Cyclone density (JMA,NIO,Ionave)
NIO
30N
27N
24N
21N
18N
15N
12N
9N
6N
3N
EQ
0
0.02
0.04
0.06
0.08
0.1
0.12
FT=0
FT=24
FT=48
FT=72
FT=96
FT=120
FT=144
FT=168
FT=192

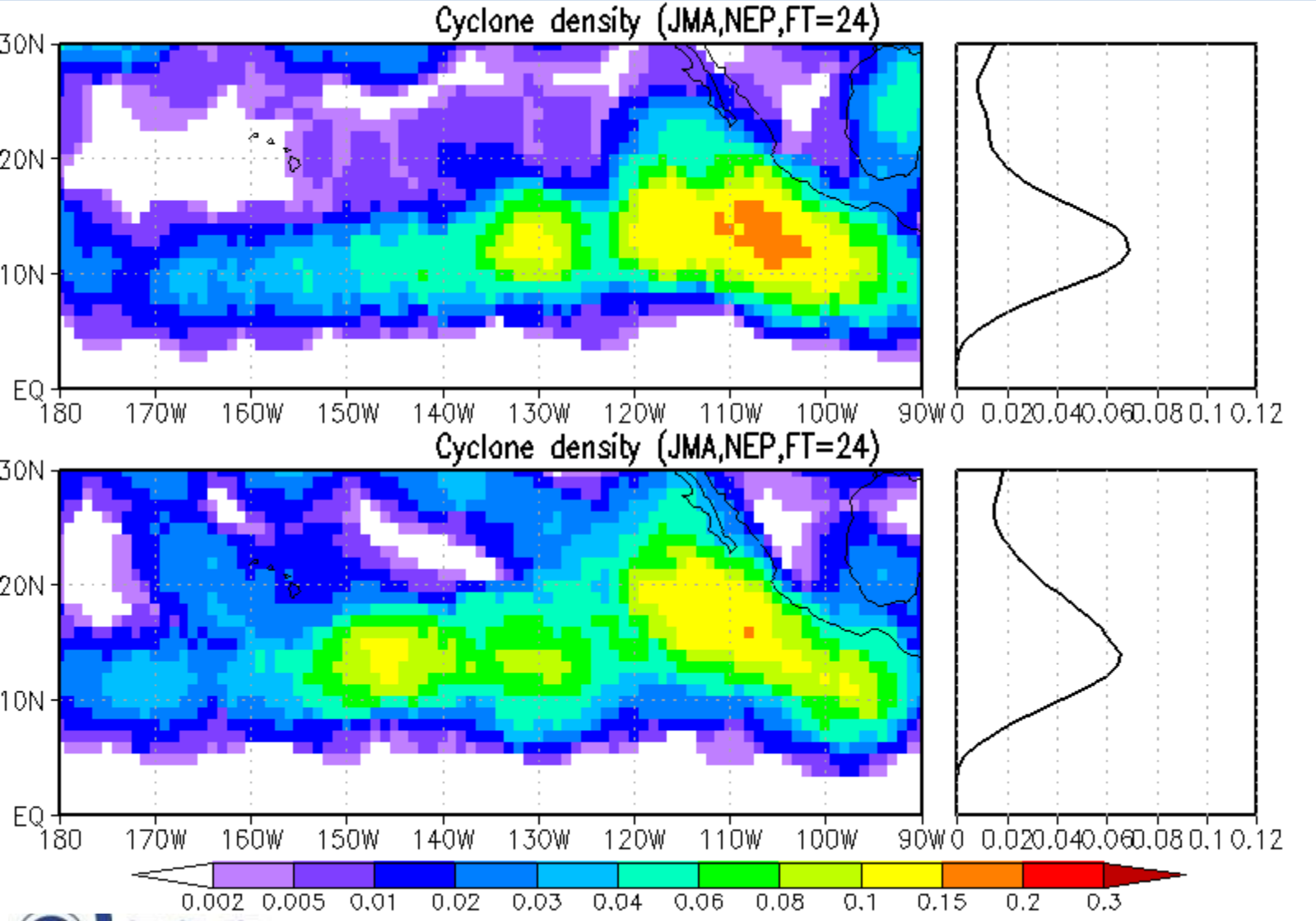
JMA (ENP, 2013 VS 2014, FT=0)



2013

2014

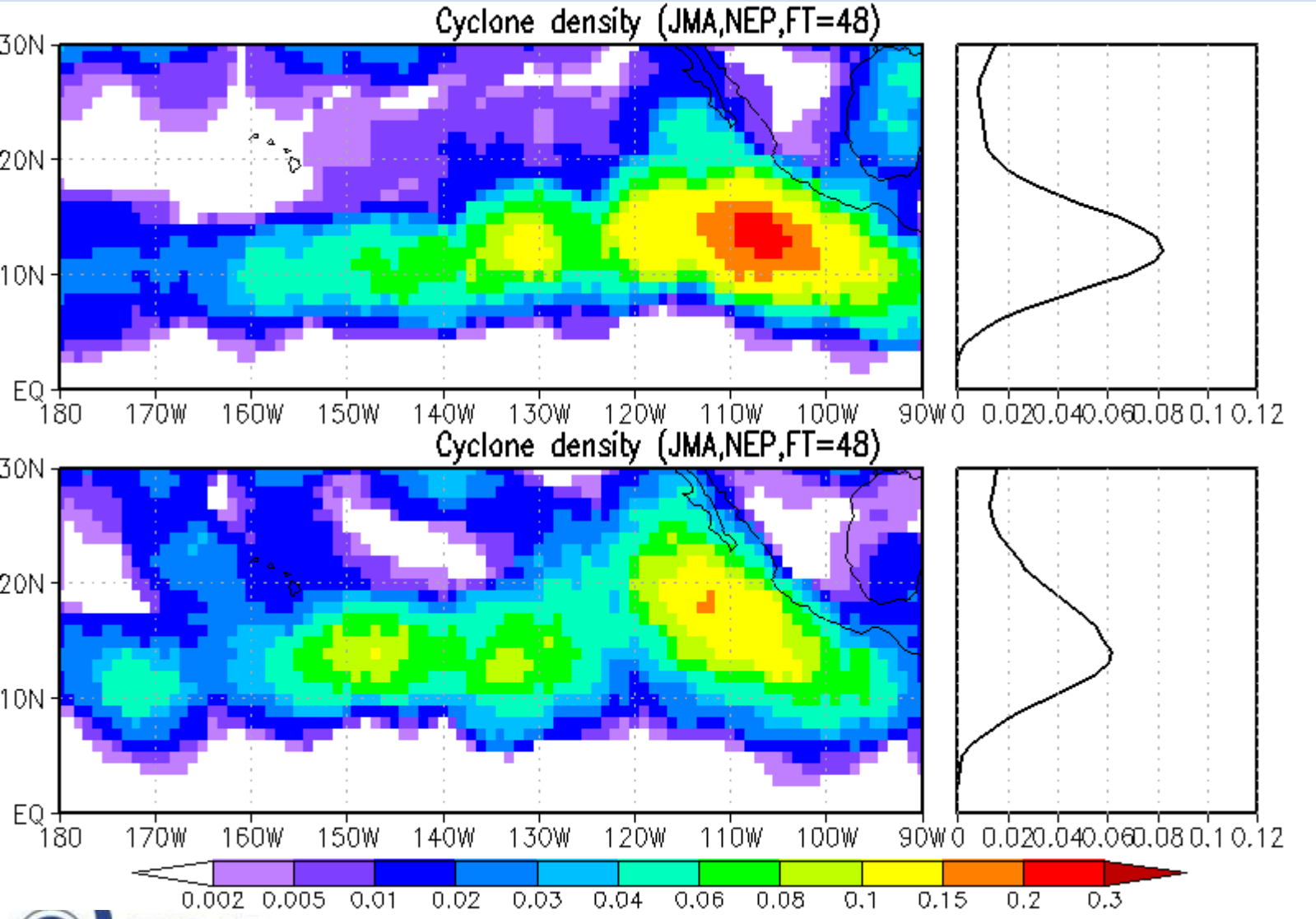
JMA (ENP, 2013 VS 2014, FT=24)



2013

2014

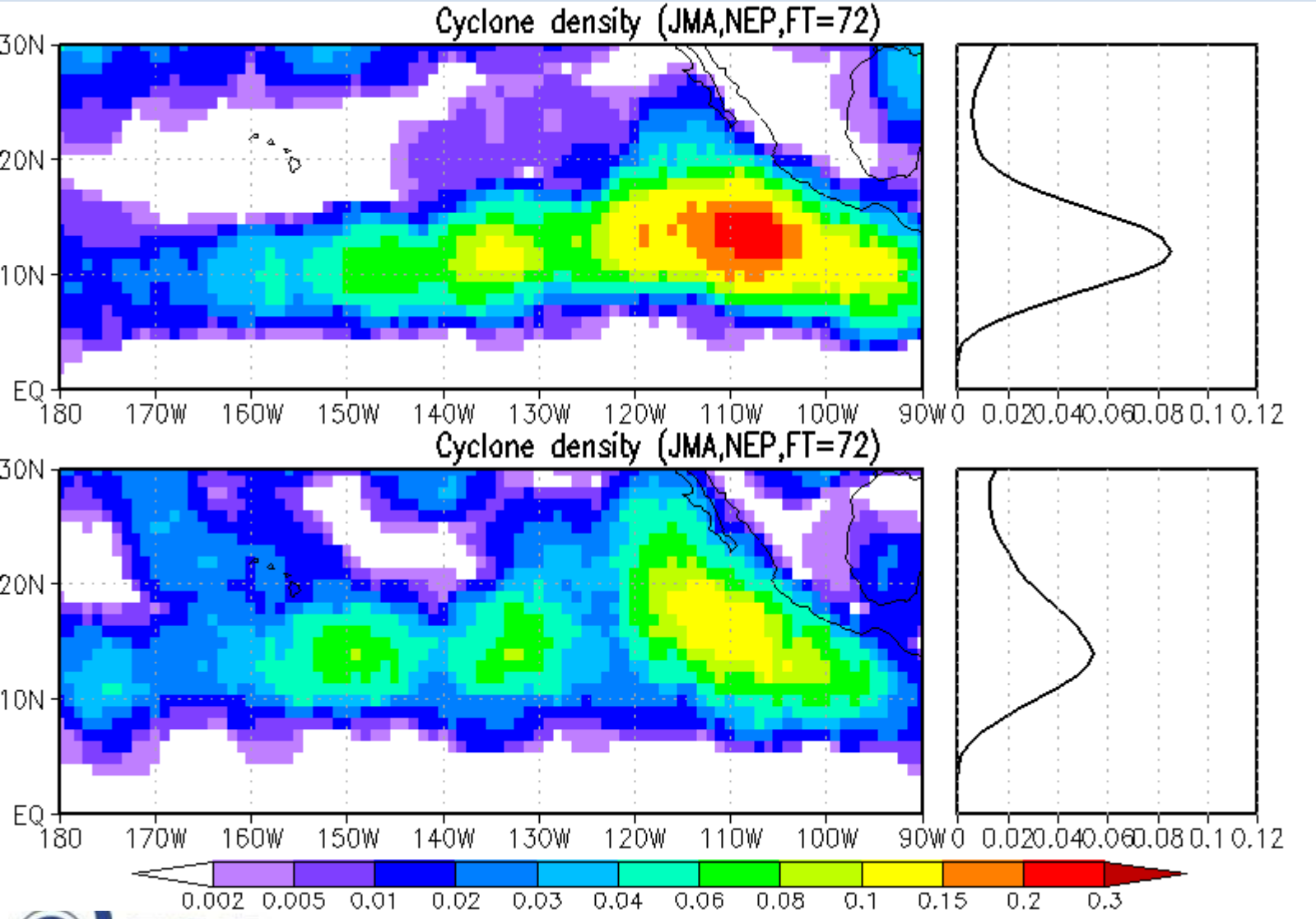
JMA (ENP, 2013 VS 2014, FT=48)



2013

2014

JMA (ENP, 2013 VS 2014, FT=72)



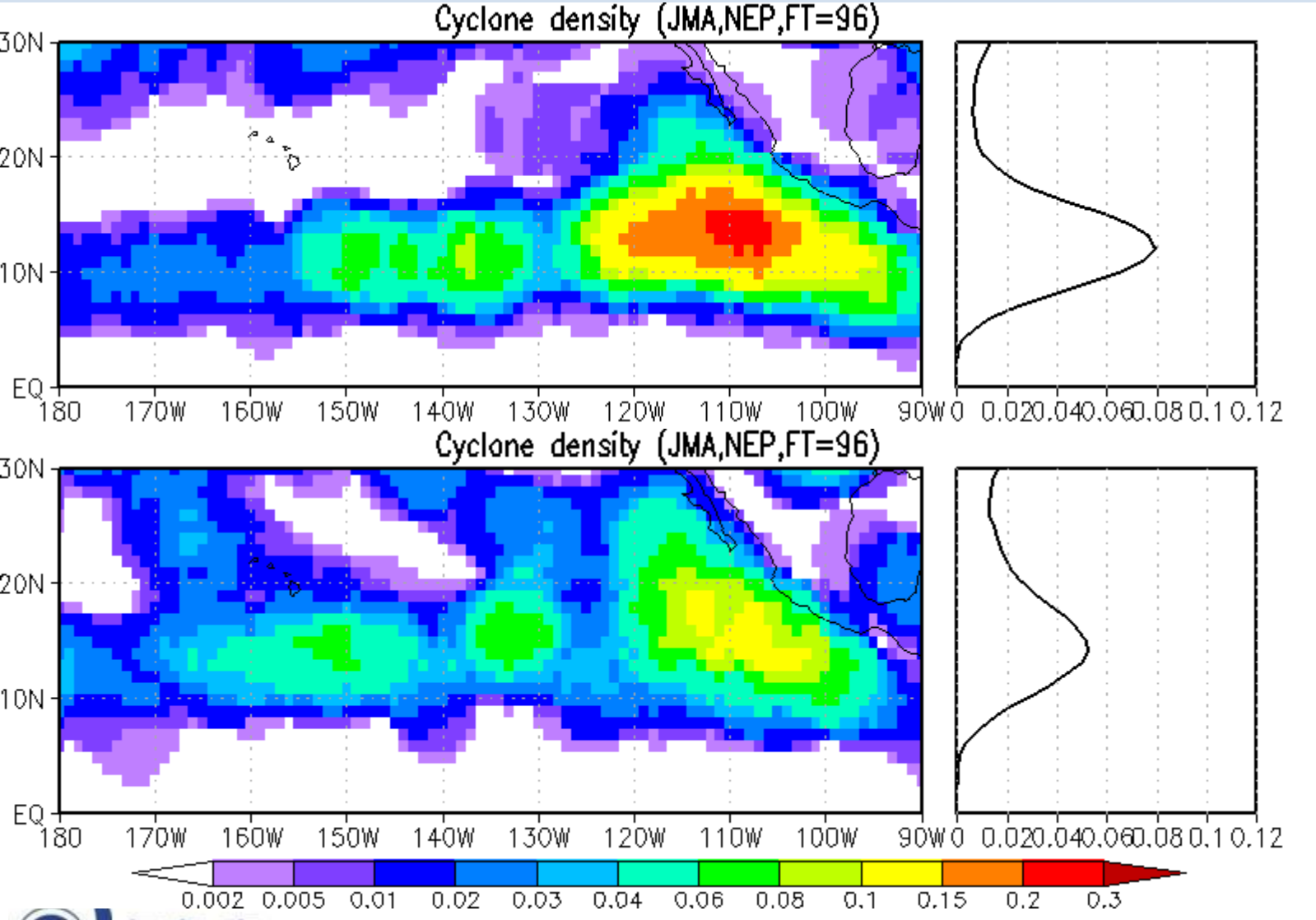
2013

2014

気象庁
Japan Meteorological Agency

JMA

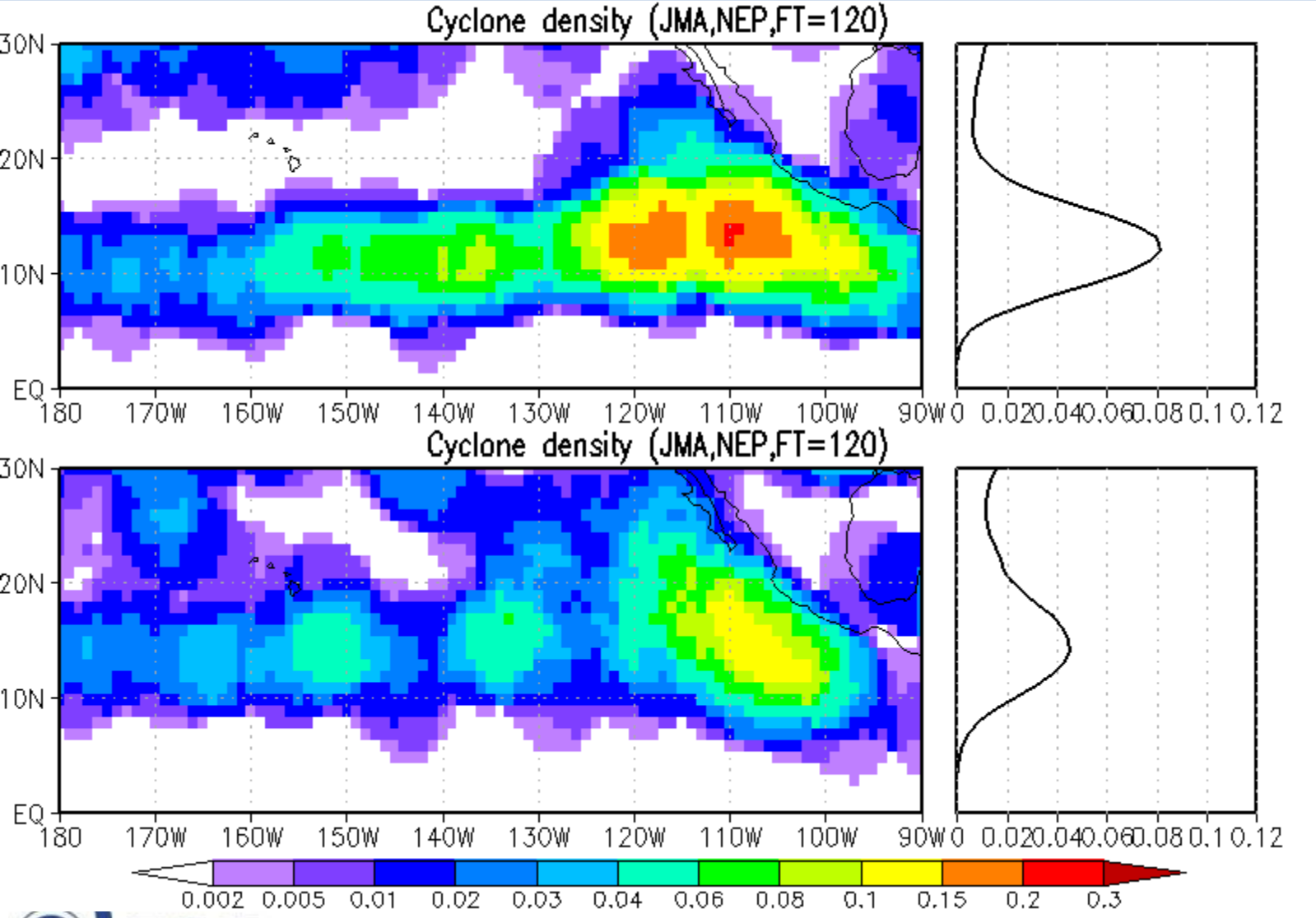
JMA (ENP, 2013 VS 2014, FT=96)



2013

2014

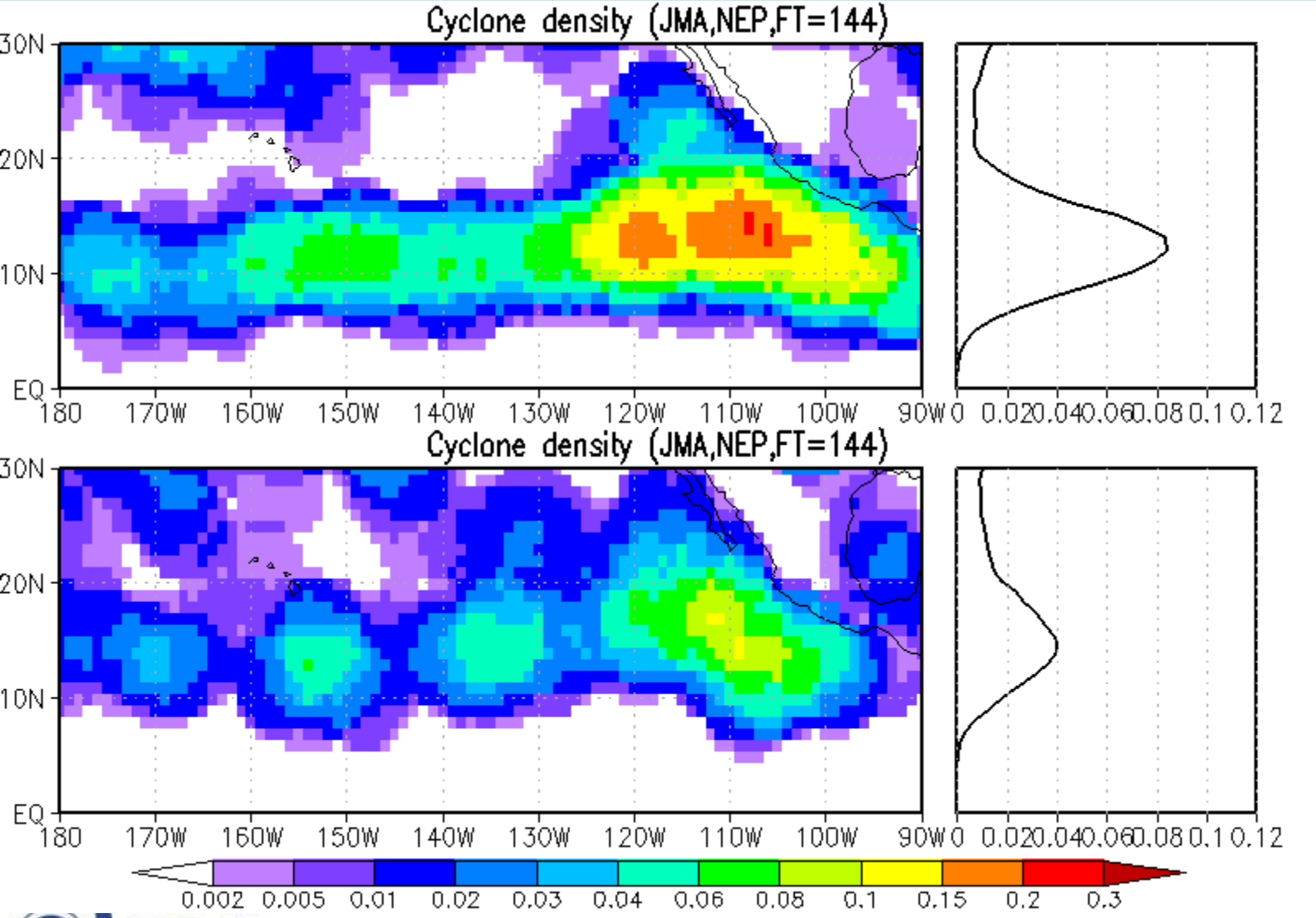
JMA (ENP, 2013 VS 2014, FT=120)



2013

2014

JMA (ENP, 2013 VS 2014, FT=144)



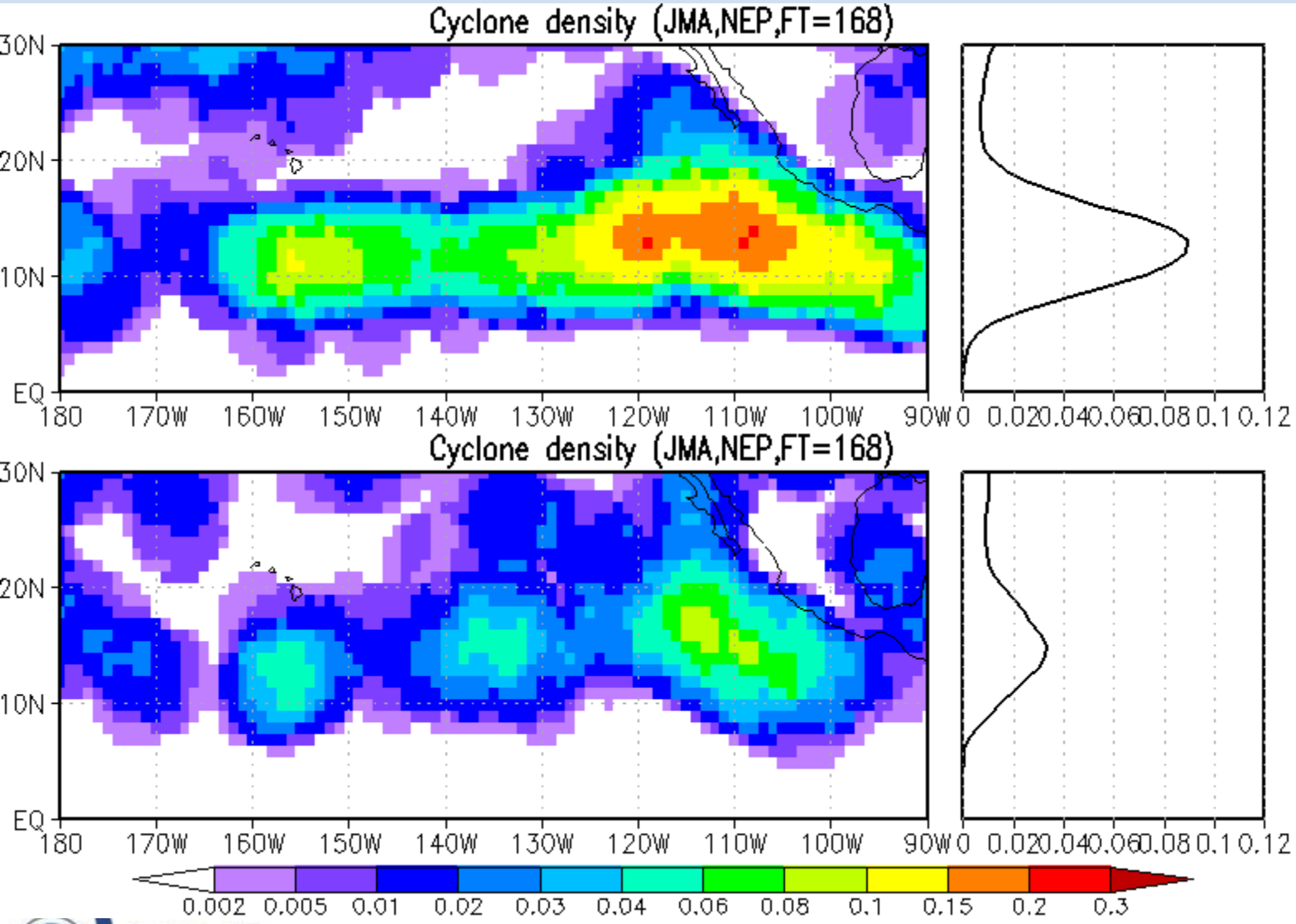
2013

2014

気象庁
Japan Meteorological Agency

JMA

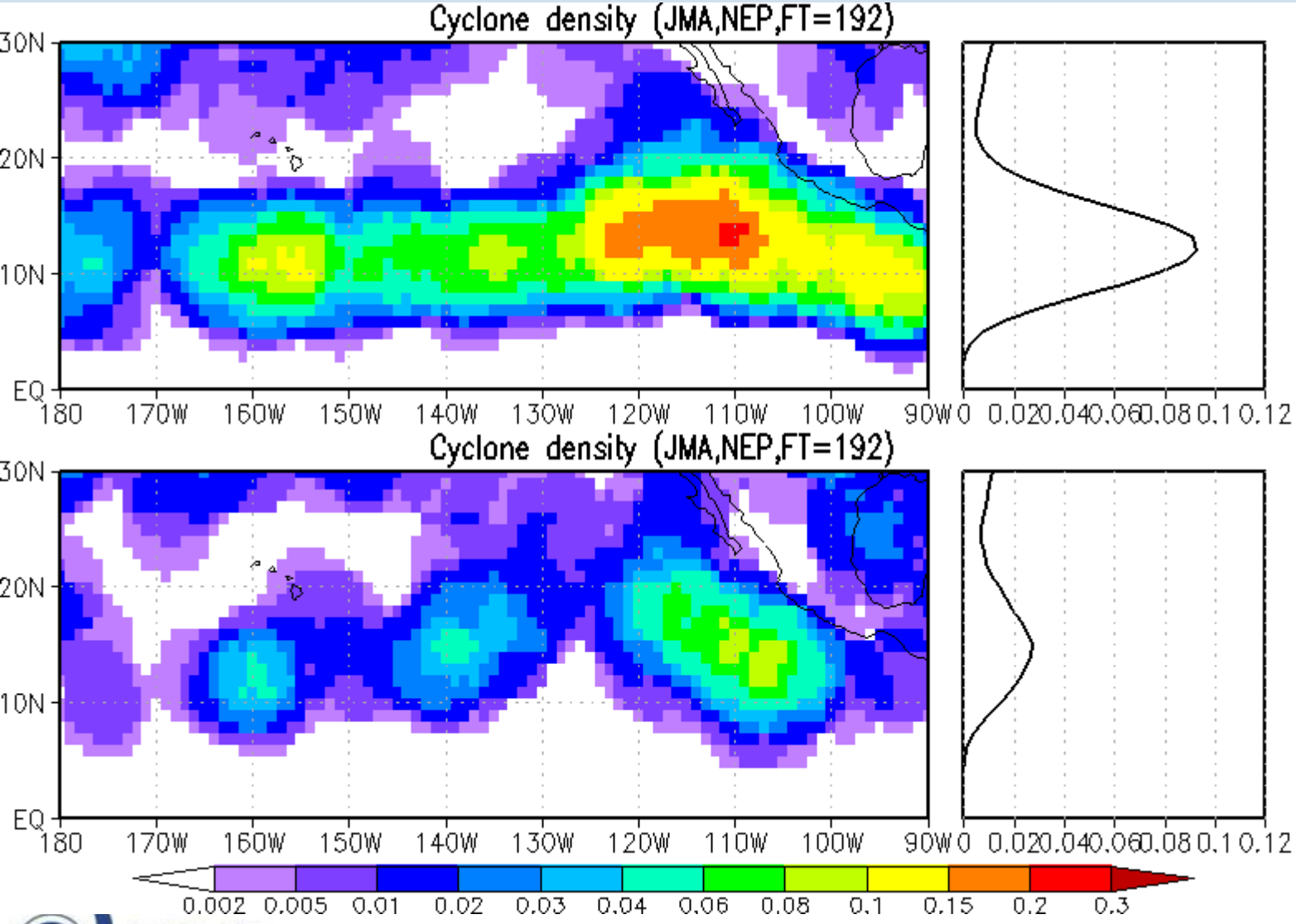
JMA (ENP, 2013 VS 2014, FT=168)



2013

2014

JMA (ENP, 2013 VS 2014, FT=192)



2013

2014

気象庁
Japan Meteorological Agency

JMA