The role of horizontal resolution in simulating tropical cyclone activity with the ECMWF Integrated Forecast System

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With the focus on …

1. Mean TC frequencies.
2. Genesis and Tracks.
3. Intensity distributions.
4. Vertical structure of the TC composites.
5. An example of the horizontal structure of intense TCs.
6. Life cycle composites.
7. An example of the evolution of an intense TC in a 10-km model: intensity fluctuations occur in connection with the variations of the eyewall/rainband structure.
8. Interannual variability

Julia V. Manganello and Co-authors, 2011: "Tropical Cyclone Climatology in a 10-km Global Atmospheric GCM: Toward Weather-Resolving Climate Modeling". *J. Climate* (in revision).

Project Athena

- **NSF impetus**: Supercomputer availability and interest in outcome of 2008 World Modeling Summit
- **Hypothesis**: Exploring high spatial resolution and process-resolving models can dramatically alter simulation of climate
- **COLA role**: formed and led an international collaboration involving **over 30 peoplein 6 groupson 3 continents**
- Two state-of-the-art global AGCMs at the **highest possible spatial resolution**
- **Dedicated supercomputer**at NICS for Oct'09 – Mar'10
- **Data ~900 TB total**
- Long term - **model output data will be invaluable** for large community of climate scientists (unprecedented resolution and simulation duration) and computational scientists (lessons learned from running dedicated production at nearly petascale)

Courtesy of Jim Kinter (COLA)

IFS Experiments

Experiment	Model	Resolution	# of Cases	Years	Length
IFS Hindcasts	T2047	10 km	19	1989-2007	395 days
	T1279 T511 T159	16 km 39 km 125 km	48	1960-2007	395 days
IFS AMIP	T1279	16 km	1	1961-2007	47 years
	T159	125 km			

- IFS is an operational weather forecast model.
- 91 levels in the vertical.
- Uses hydrostatic approximation and parameterized convection.
- No tuning or other changes to the parameterizations, except that in the model code, a convective adjustment time-scale has a resolution-dependent term.
- All runs are initialized on November 1.
- SST and sea ice are the same 1.125° used for the ERA-40 reanalysis (monthly – before 1990; weekly – starting 1990; daily – starting 2002).

Tracking and Identification of TCs

1. Hodges Method for detection and tracking of tropical vortices:

- 850-hPa relative vorticity max (NH) of 5×10^{-6} s^{-1} at T42,
- Lifetime ≥ 2 days.
- Displacement distance filter (displacement distance of the selected vortices should satisfy a min of 10° (~1,000 km) over their lifetime).

2. TC Identification Criteria:

	T2047	T1279	T511	T159
1. Surface (10-m) wind speed threshold, m/s.	15.4[1]	15.4[1]	14.1[2]	11.9[2]
2. Difference in vorticity between 850 hPa and 250 hPa (a warm core condition).	larger than zero			
3. Vorticity max at each level between 850 hPa and 250 hPa (a coherent vertical structure condition).	satisfied for all resolutions			
4.Criteria 1-3 are satisfied for at least 4 consecutive time steps (24 hours).	satisfied for all resolutions			
5. Cyclogenesis (first identification)occurs between 0-20°N over land and 0-30°N over oceans.	satisfied for all resolutions			

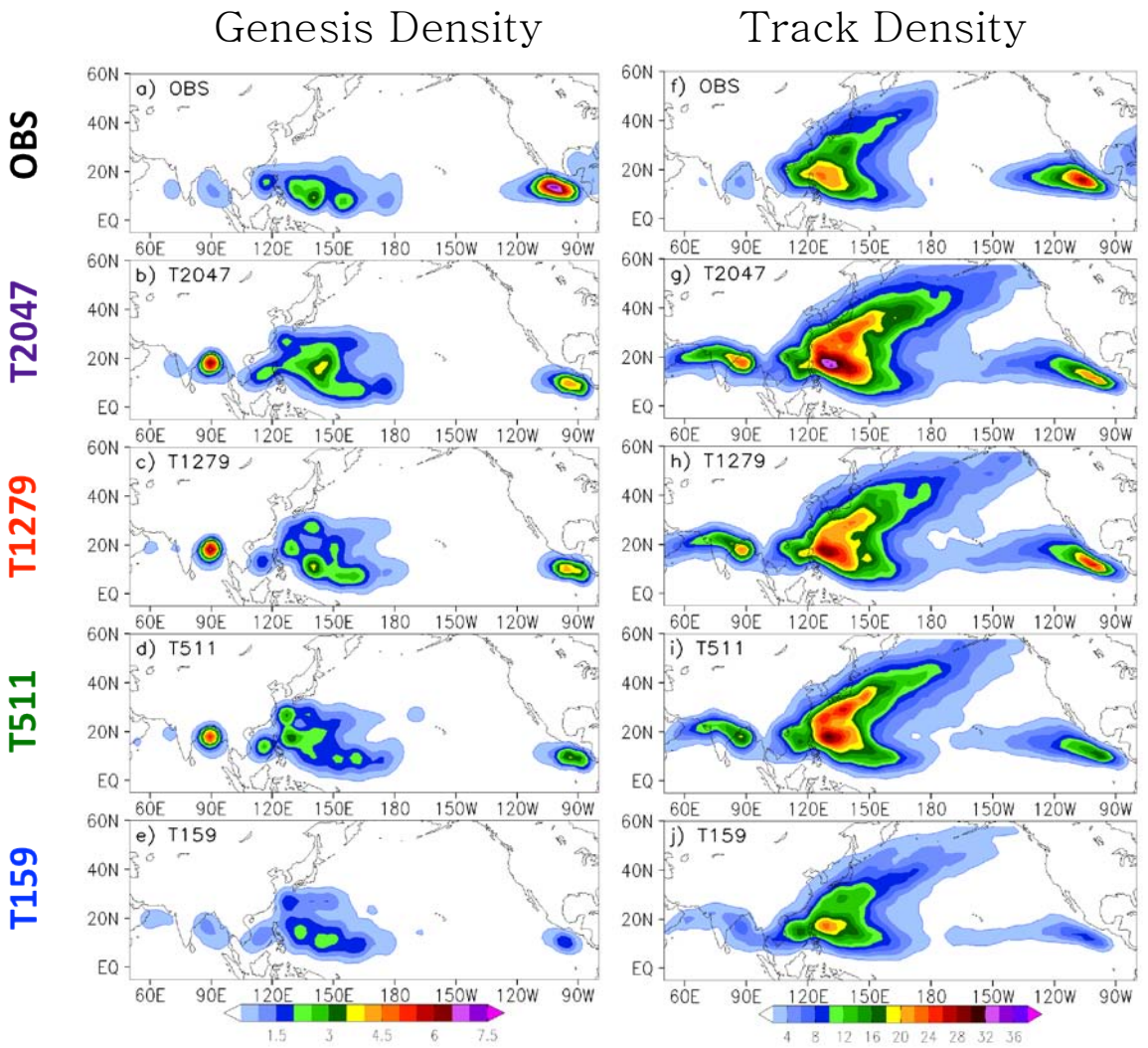
[1] Observed "tropical storm" threshold for 10-min max. sustained wind. $U_{10min} = 0.88 * U_{1min}$

[2] Adjusted for model time step and resolution. $U_{10min} = 1.03 * U_{1hr}$

Tracking and Identification of TCs, cont.

- Analysis for the Northern Hemisphere (NH) only.
- March-November (MJJASON) season of 1990-2008.
- OBS:
  - IBTrACS version v02r01.
  - Processed imposing conditions 1 and 4 of the TC Identification Criteria.

TC counts, Genesis and Tracks
(North Pacific and the North Indian Ocean)



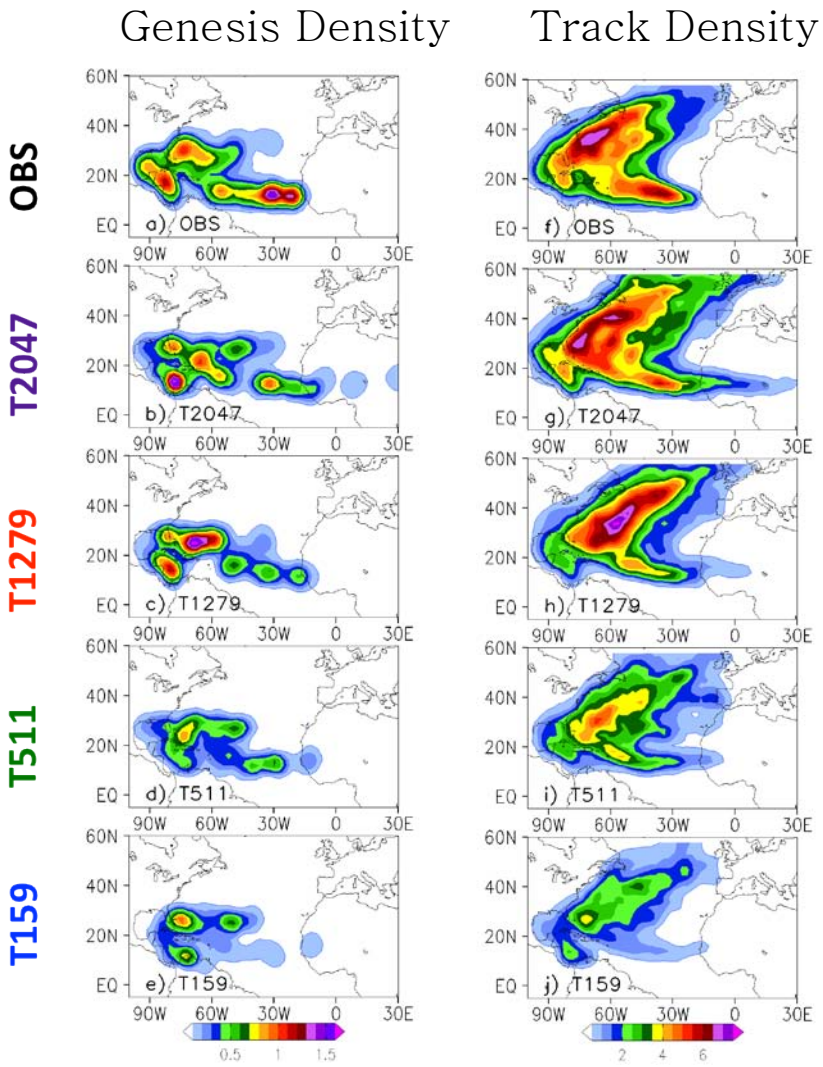
Mean TC frequency

	OBS	T2047	T1279	T511	T159
NH	55.4	**73.7**	**62.3**	59.6	**42.7**
NW Pac	23.8	**39.0**	**31.2**	**32.1**	25.7
N Ind	4.4	**9.9**	**8.7**	**7.9**	4.8
NE Pac	14.8	12.9	12.7	**11.3**	**5.9**

•Units are numbers per season.

• Model values in bold are significantly different from the OBS (at 95% confidence level).

TC counts, Genesis and Tracks
(North Atlantic)



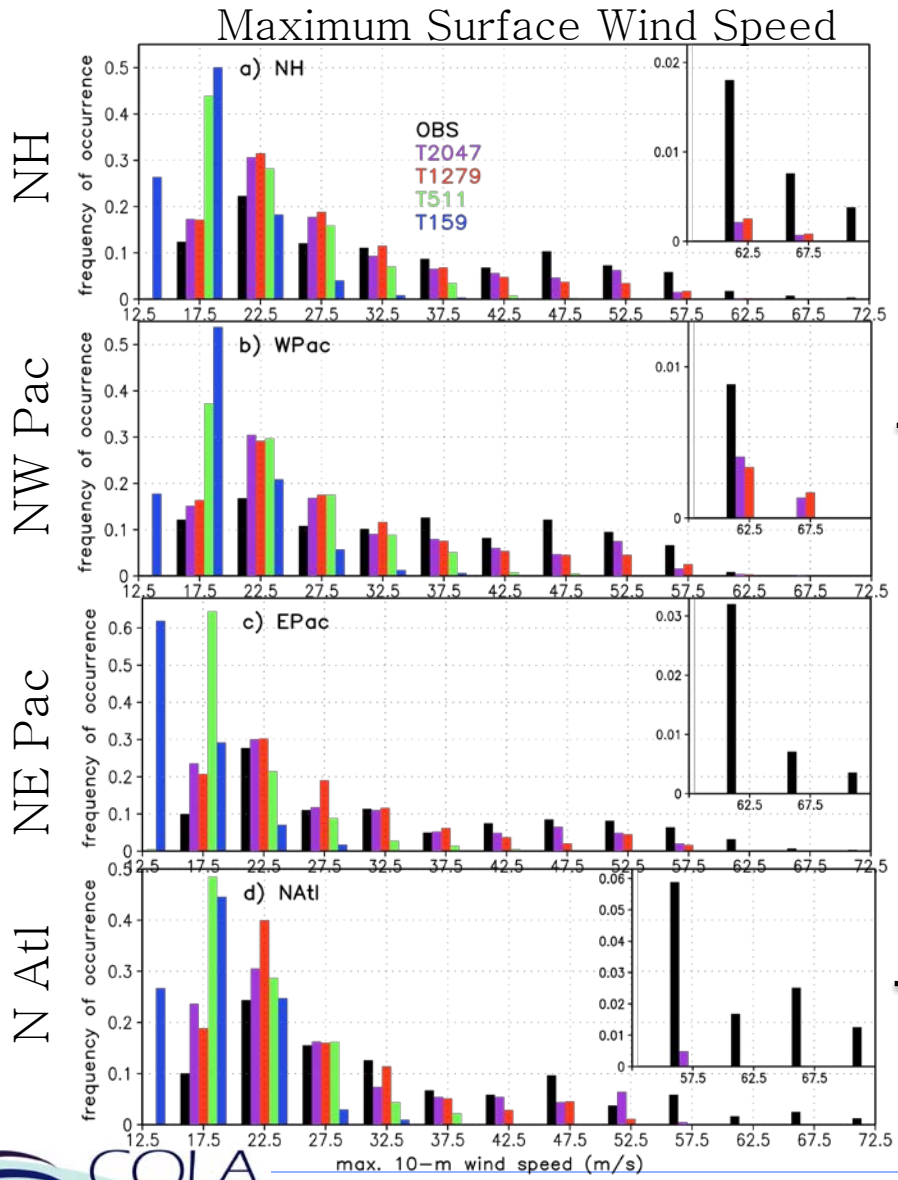
Mean TC frequency

	OBS	T2047	T1279	T511	T159
N Atl	12.5	10.7	**9.2**	**7.2**	**5.3**

•Units are numbers per season.

• Model values in bold are significantly different from the OBS (at 95% confidence level).

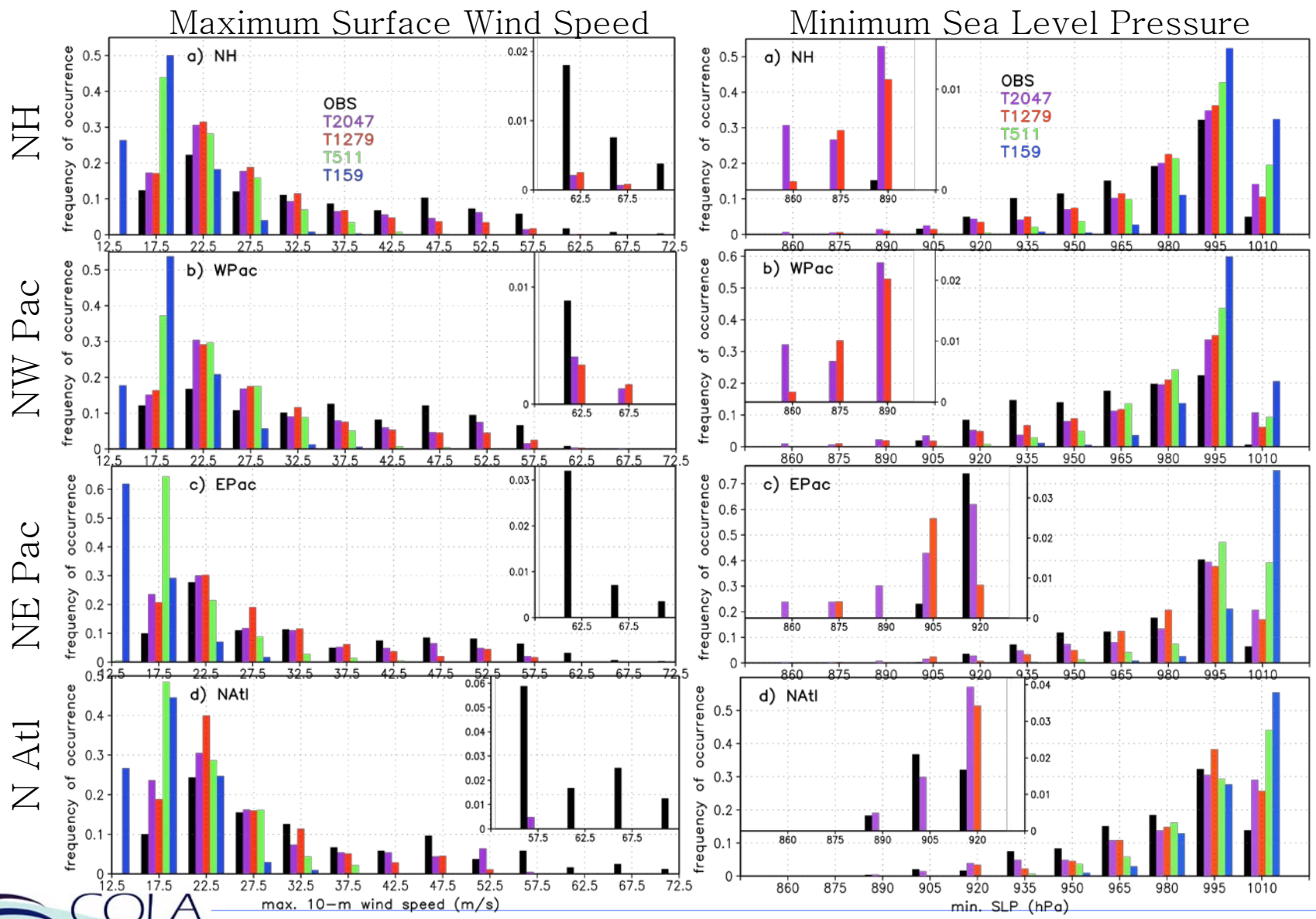
Intensity Distribution



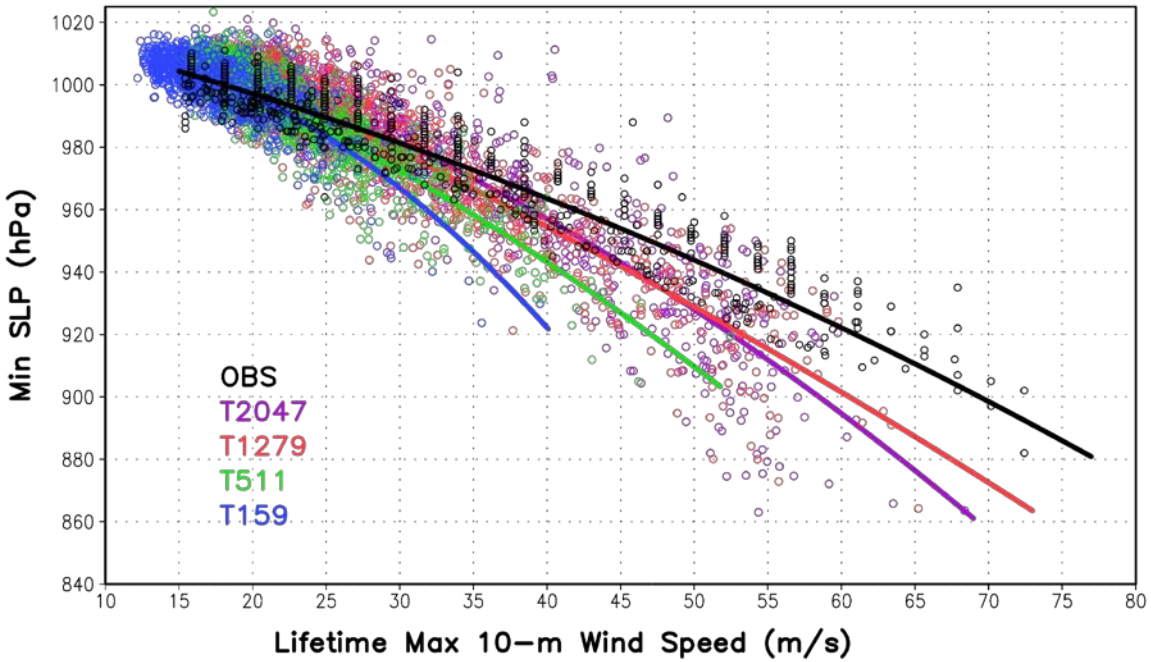
	T2047	T1279	T511	T159
Most intense TC, m/s	68.4	65.2	46.4	29.9

Most intense TC at T2047:
56.6 m/s (CAT 4)

Intensity Distribution

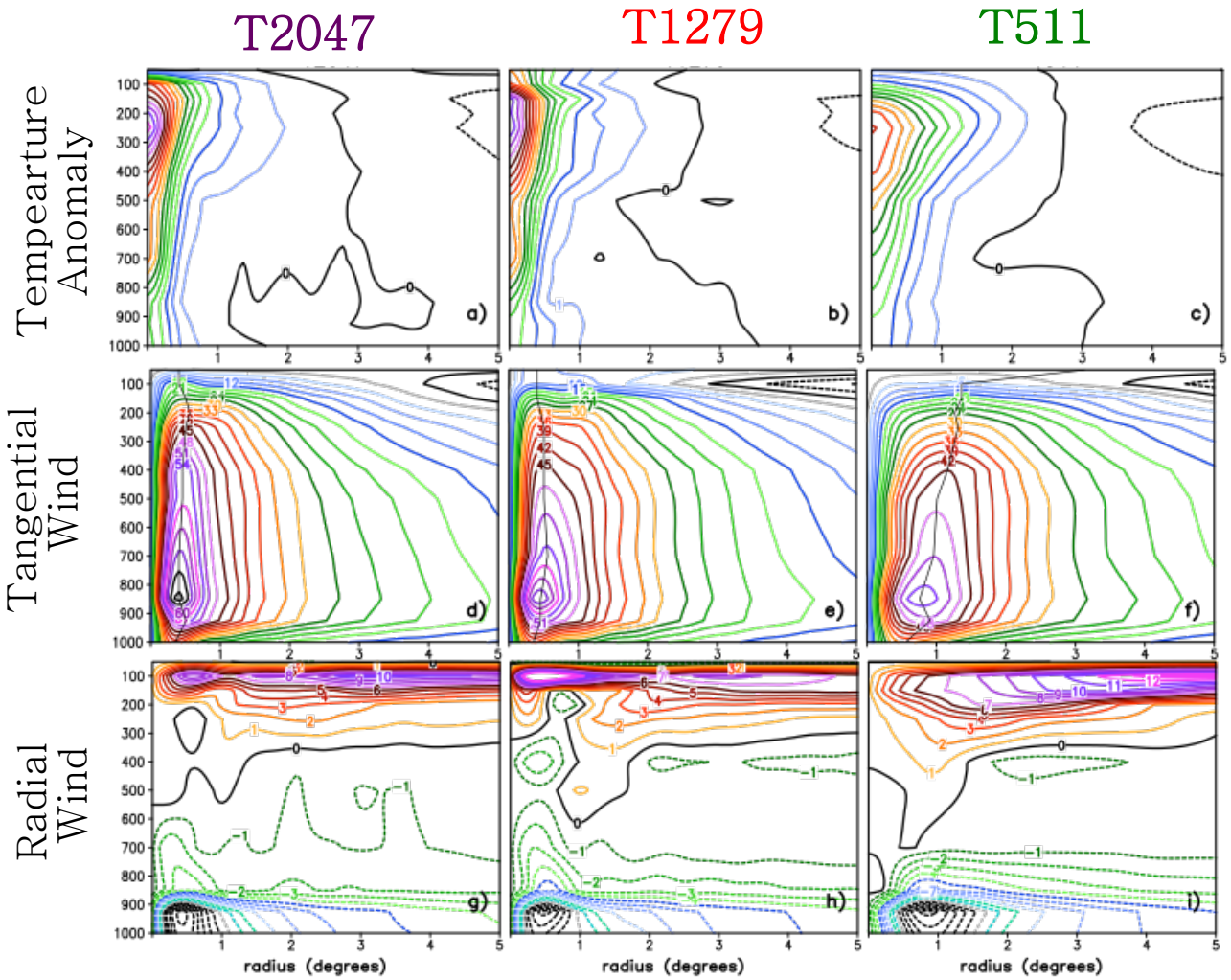


Wind-Pressure Relationship



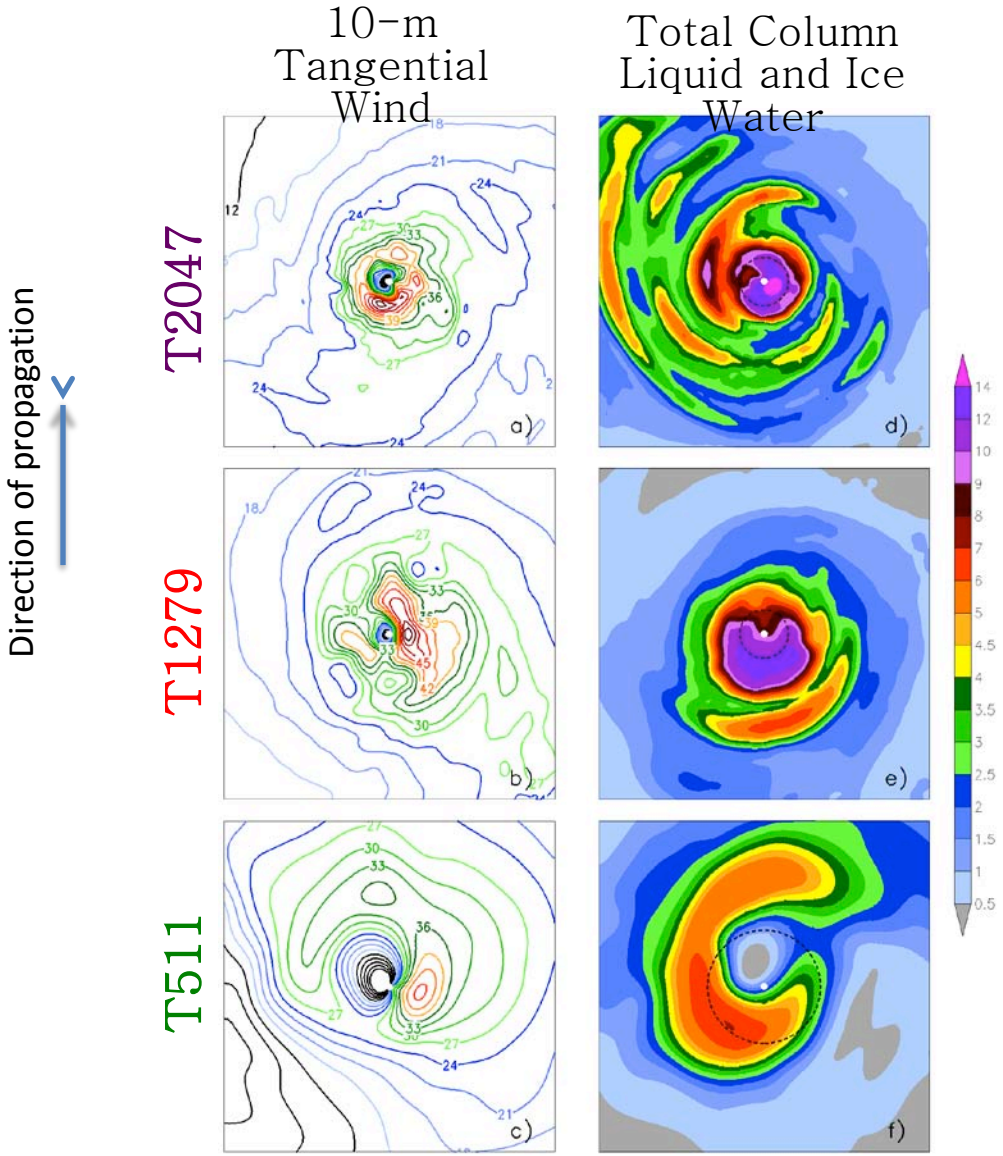
- Deficiencies in surface momentum flux parameterization (surface roughness too high in the high wind speed range)?
- Need to go to even higher resolutions?
- Explicit convection?

Vertical Structure of the TC Composites



Composites are formed by averaging five of the most intense storms (in terms of the 10-m wind speed) at the time when they achieve their maximum intensity.

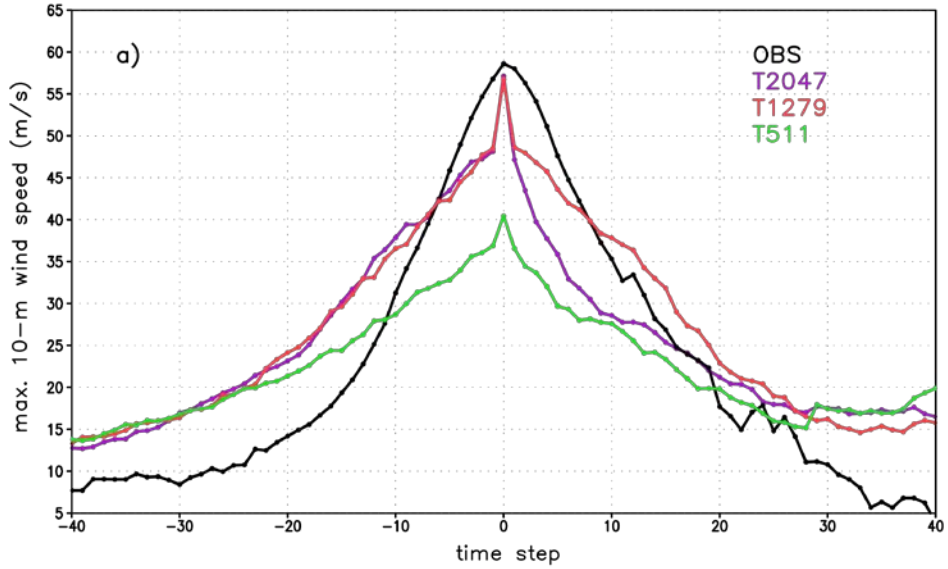
Horizontal Structure of the most intense TCs



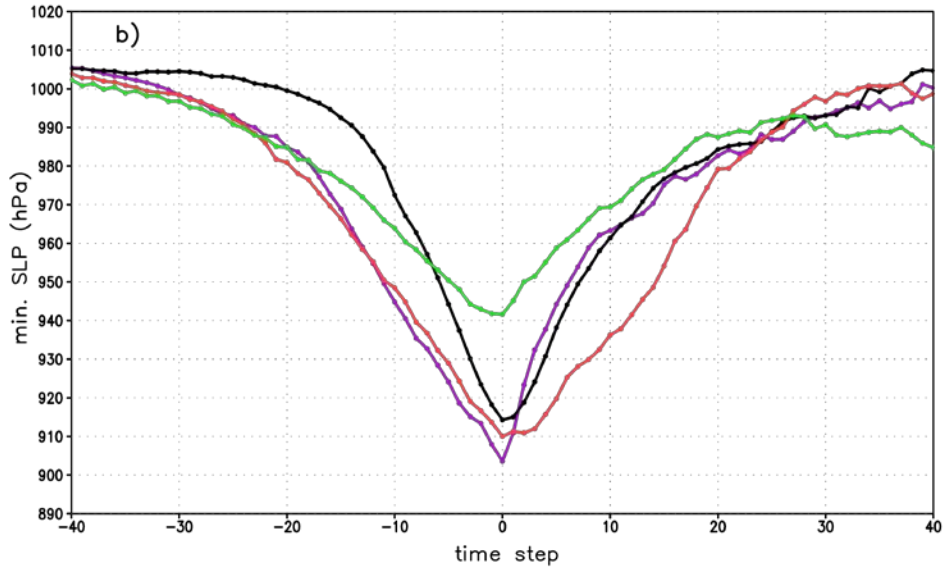
- Radius is 2° from the storm center

Life Cycle Composite

Max surface Wind Speed

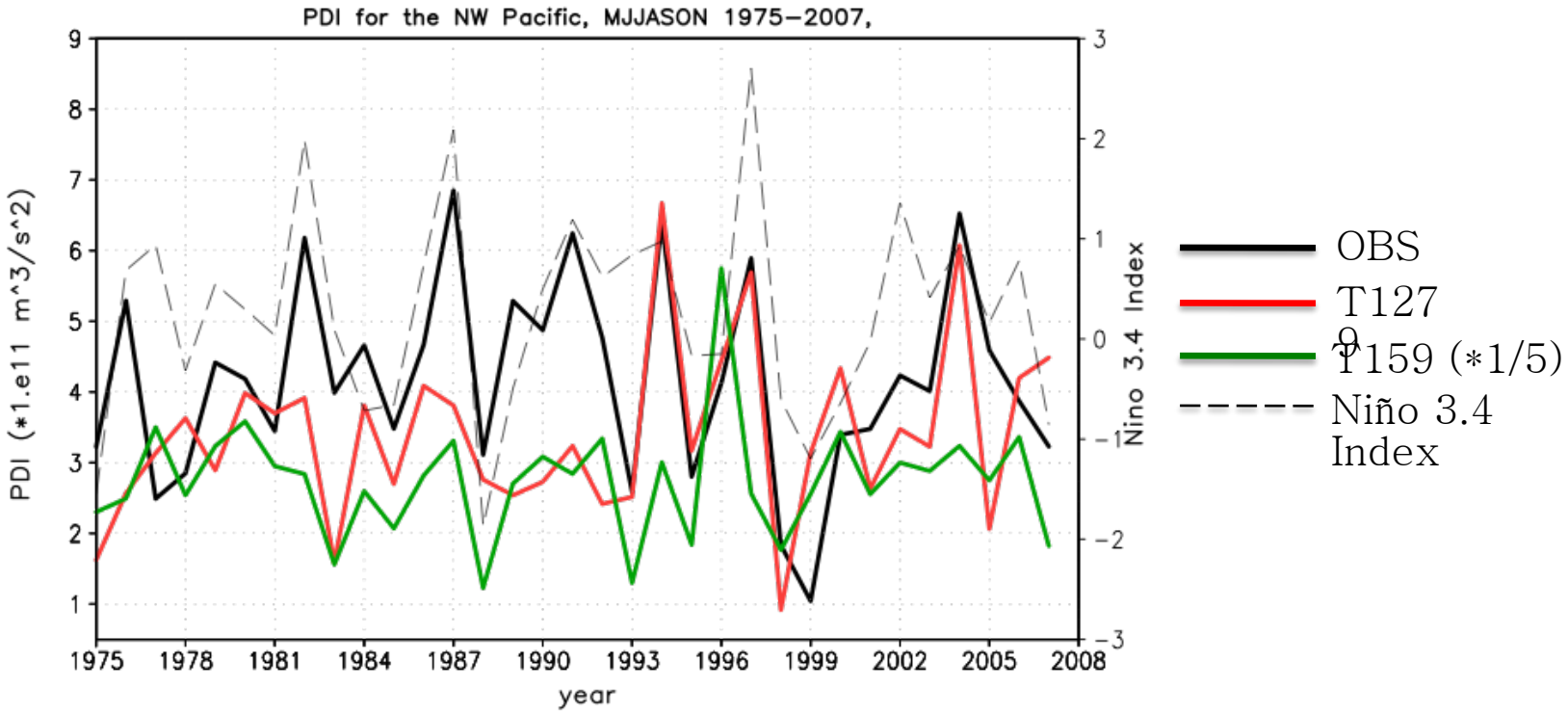


Min SLP



- Based on the 25 most intense typhoons in the northwest Pacific.
- Time step is in 6-hr increments.

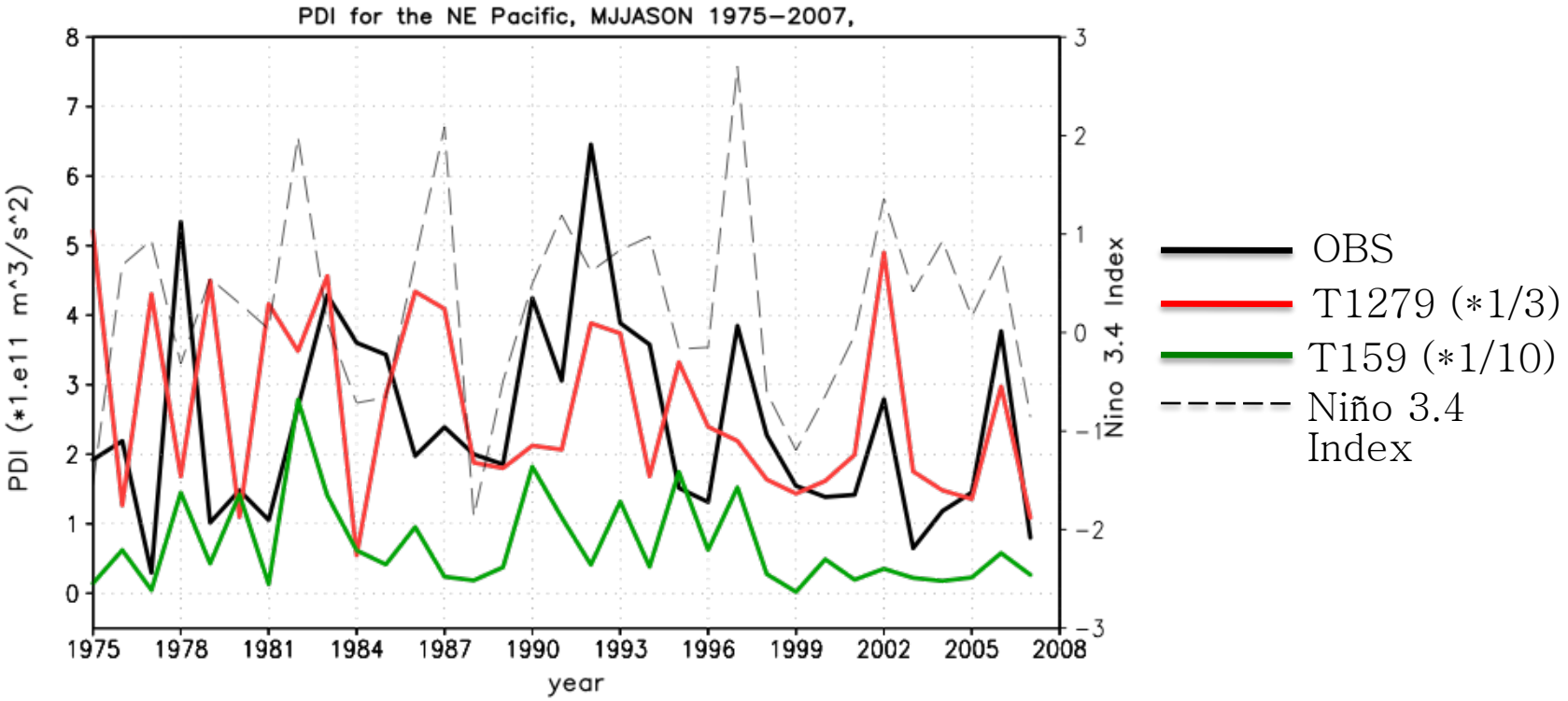
Interannual Variability of the PDI (Northwest Pacific; AMIP 1975-2007)



	OBS	T1279	T159
Difference between **active and inactive** years, *1.e10	**31.8**	**13.9**	**19.5**
Changefrom 1975-1989 to 1993-2007, *1.e10	-4.1	7.8	2.4
Difference between **El Niño and La Niña**years, *1.e10	**20.0**	**14.5**	9.0

- values in bold are significant at 95% confidence level.

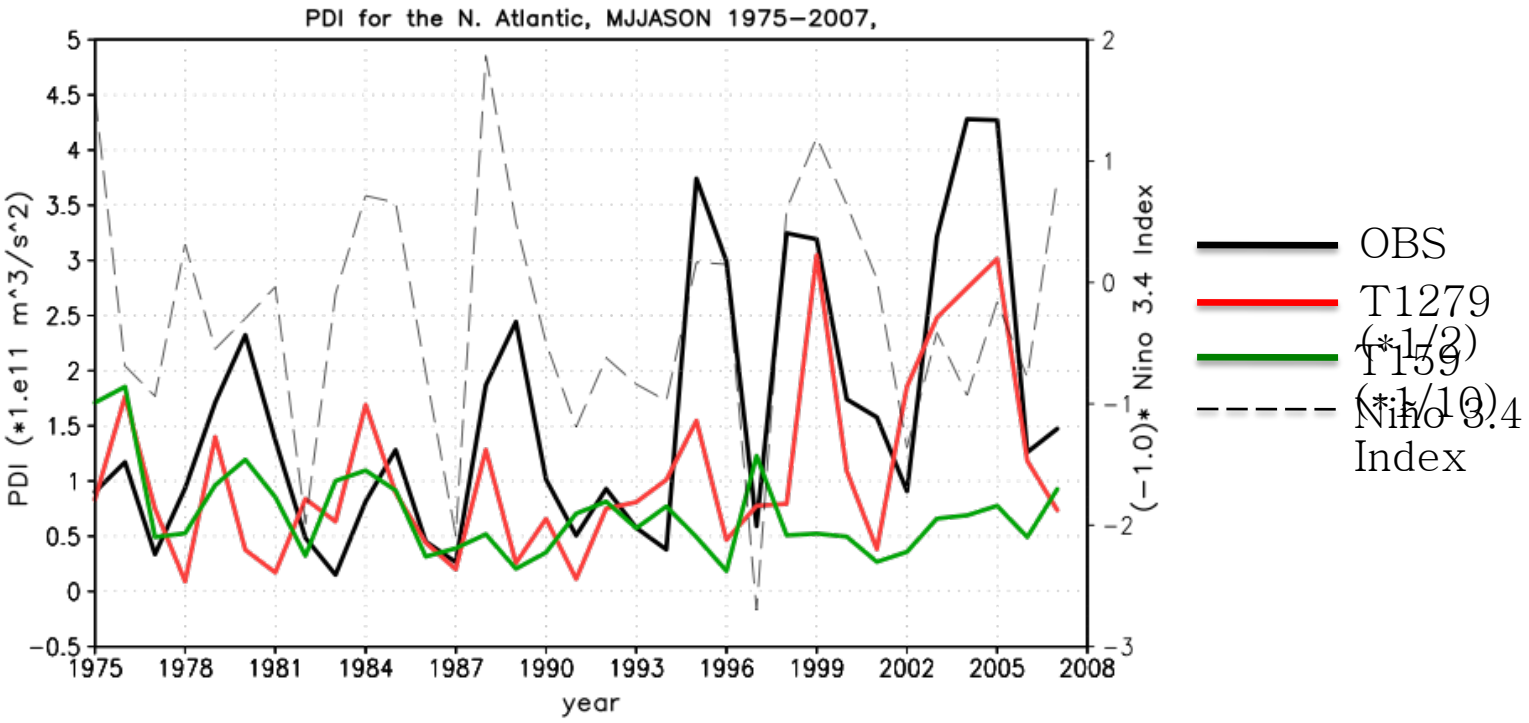
Interannual Variability of the PDI (Northeast Pacific; AMIP 1975-2007)



	OBS	T1279	T159
Difference between **active and inactive** years, *1.e10	**31.4**	-0.5	9.1
Changefrom 1975-1989 to 1993-2007, *1.e10	-2.7	-8.8	-4.1
Difference between **El Niño and La Niña**years, *1.e10	1.7	**14.9**	10.8

- values in bold are significant at 95% confidence level.

Interannual Variability of the PDI (North Atlantic; AMIP 1975–2007)



	OBS	T1279	T159
Difference between **active and inactive** years, *1.e10	**24.4**	**11.0**	-0.5
Changefrom 1975-1989 to 1993-2007, *1.e10	**11.3**	**10.1**	-6.9
Difference between **El Niño and La Niña**years, *1.e10	**-9.7**	-2.2	-4.1

- values in bold are significant at 95% confidence level.

Summary and Conclusions

•Horizontal resolution has a considerable influence on practically all the aspects of the simulated TC activity that we have examined.

•Overall, the 10-km version of IFS produces the most realistic simulation of the TC statistics compared to the lower resolution versions.

- ✓ Large-scale model biases could mask the potential benefit of the higher resolution.
- ✓ The limiting effects of physical parameterizations (e.g., surface momentum flux, convective) need to be clarified.

• The largest benefits of the highest resolution simulations are the dramatically more accurate representation of the TC intensity distribution, 3-D structure and the intensity life cycle.

Hydrostatic model with cumulus parameterization and of high enough resolution could be efficiently used to simulate the TC intensity response (and the associated structural changes) to future climate change.