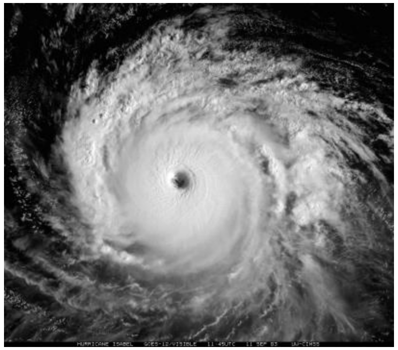

High-resolution CAM5 simulations of current and future climate

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Stony Brook University - NCAR

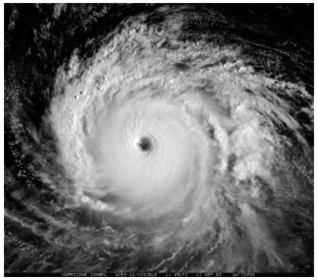
Julio Bacmeister, Cecile Hannay,
Peter Lauritzen & John Truesdale

NCAR

Michael Wehner

DOE-LBNL

TCCIP 2015 IWCC



Background

- There is a large effort at National Center for Atmospheric Research and Dept. of Energy to develop a next-generation, high-resolution Community Atmosphere Model (CAM)
- Targeting horizontal resolution of ~25 km globally.
- Focus for this talk:
  - General precipitation analysis with various high-resolution CAM5 versions simulations.
  - More detailed discussion of tropical cyclones (TCs) and the impact of model design choices.
  - Future climate simulations.
  - Call for earlier evaluation, using reduced complexity testbeds, of high-resolution model's ability to simulate extremes.

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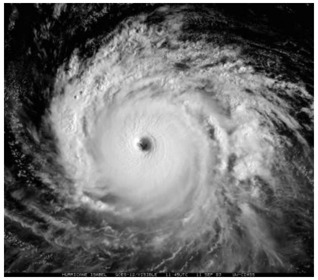
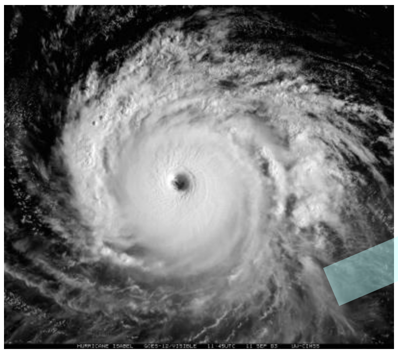


Design of Experiments

- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5 (CAM 5).
- The default Spectral Element SE dynamical core with 30 vertical levels is used at the horizontal resolution of ne120 (~25 km) – with ne30 (~100 km) run for comparison.
- This is comparable to previous DOE-LBNL CAM5-FV 0.23^{o}x0.31^{o} run.
- Full Atmospheric Model Intercomparison Project (AMIP) protocols for 1980-2005.
- Prescribed observed SSTs, ozone, CO_2, solar forcing, etc.
- GFDL tracking code is used for calculating all TC tracks.



Precipitation

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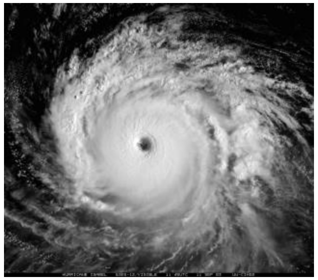
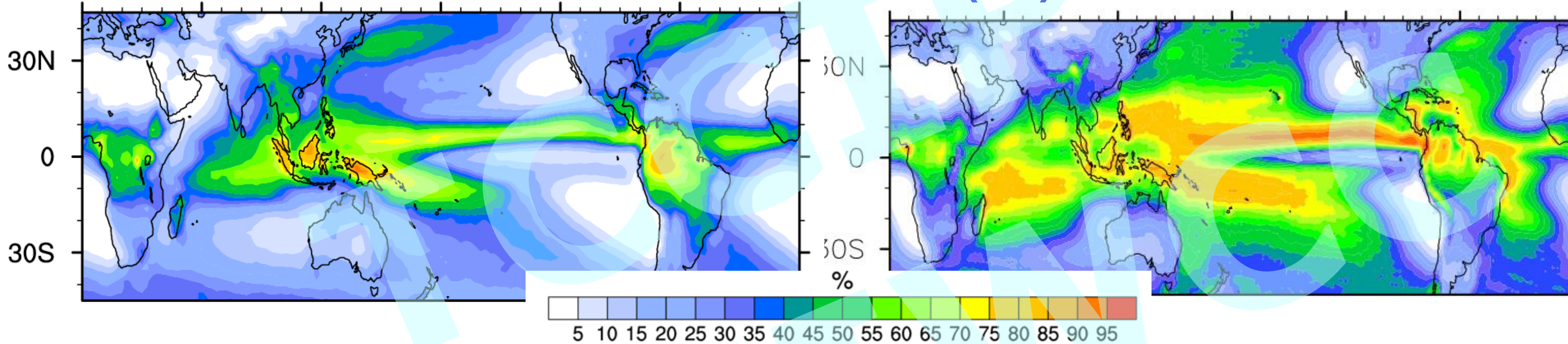
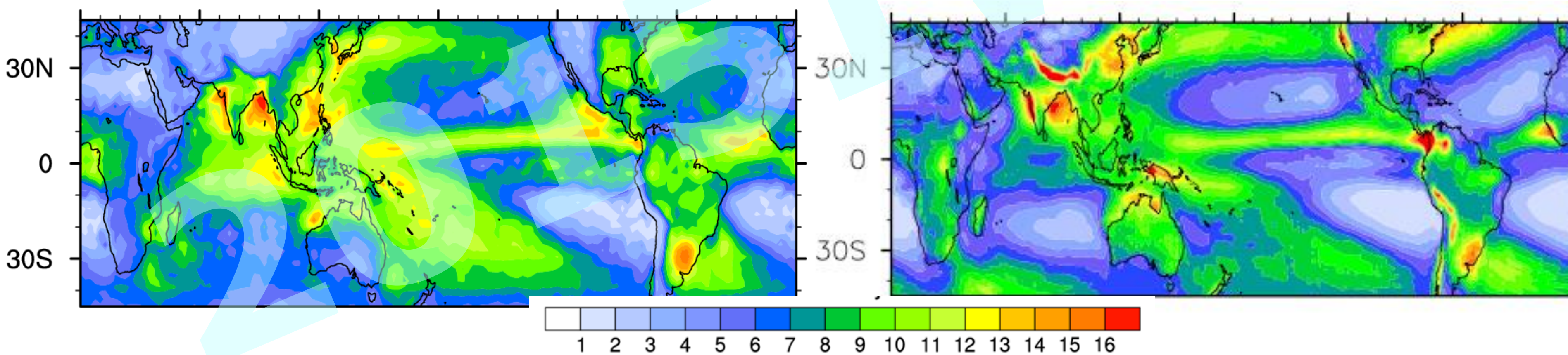


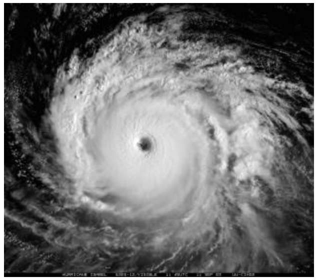
Resolution Improvement

TRMM: Precip frequency (%) — **CAM (1°) => rains too often**



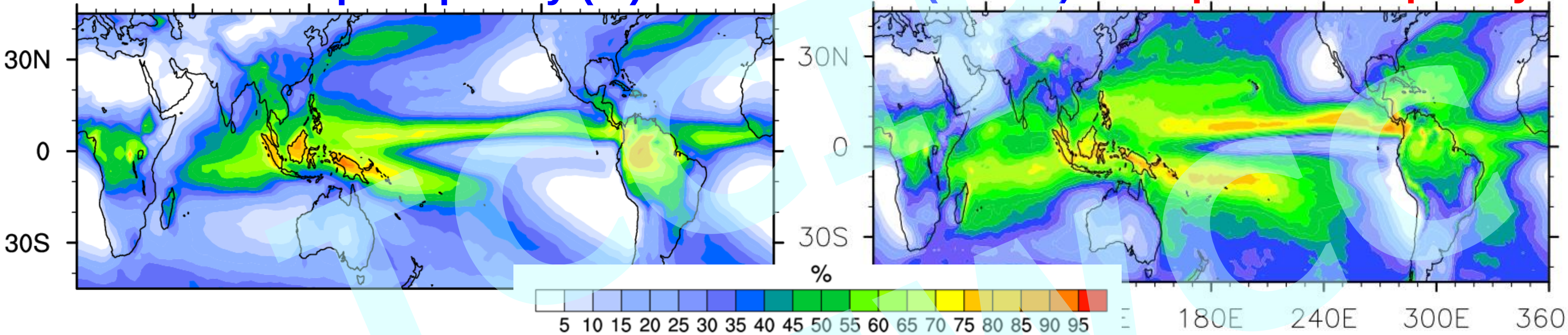
TRMM: Precip intensity (mm/day) — **CAM (1°) but not hard enough**



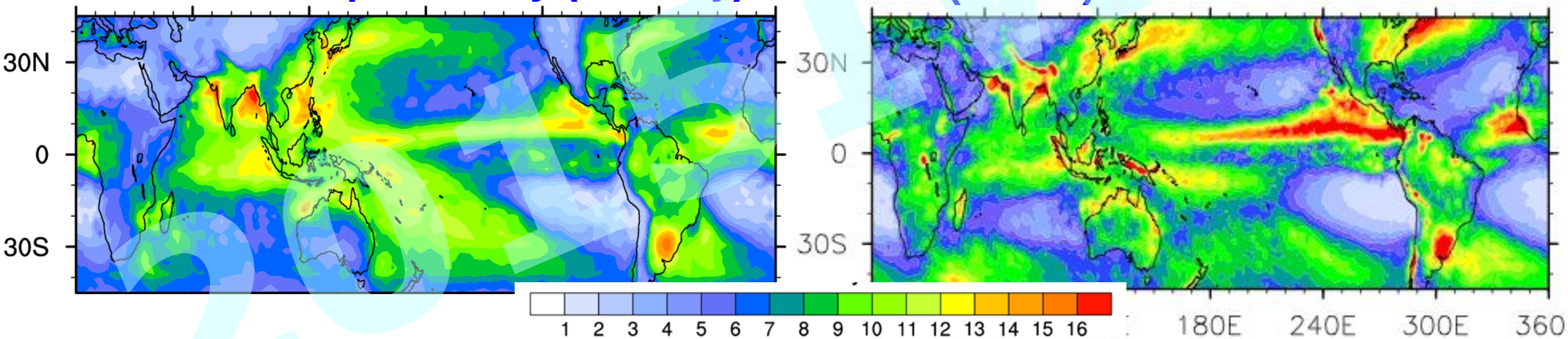


Resolution Improvement

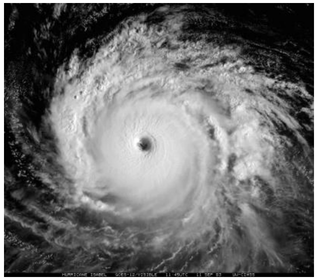
TRMM: Precip frequency (%) **CAM (0.25°) => improved frequency**



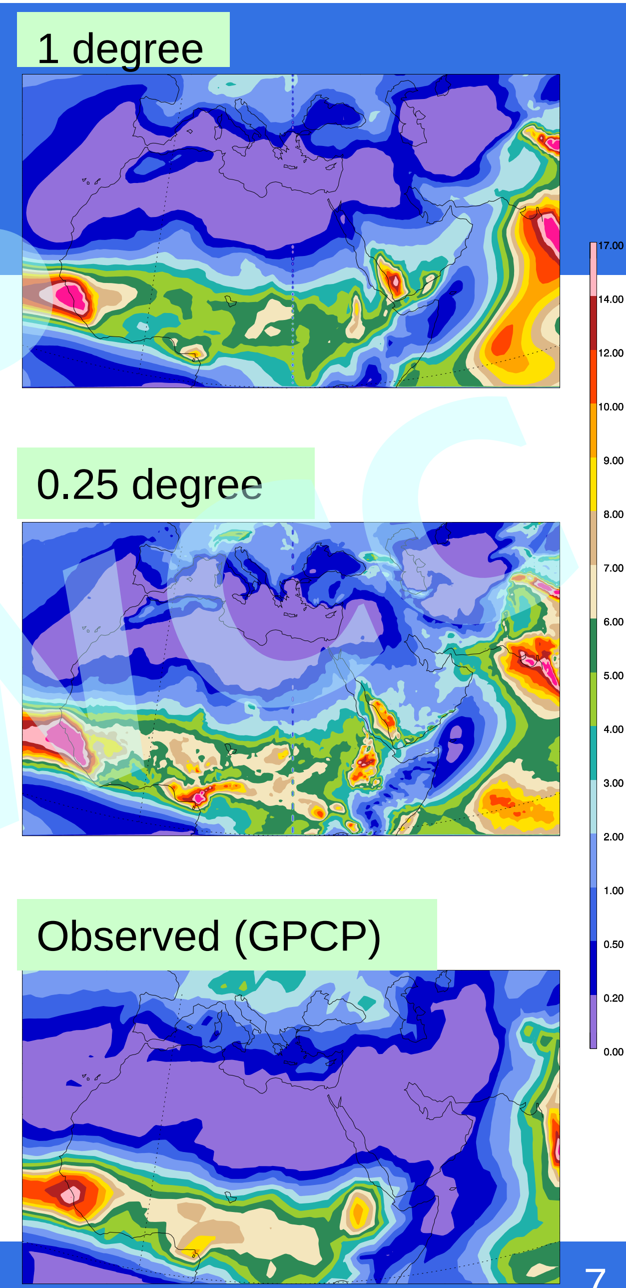
TRMM: Precip intensity (mm/day) **CAM (0.25°) => mixed result**



Problems persist at higher resolution (despite some improvements) !



Regional



West Africa - JJA

Precipitation simulation improves over W Africa as resolution increases from 1º (100km) to 0.25º (25km)

Increase in rainfall at 0.25º is associated with stronger westward moving disturbances

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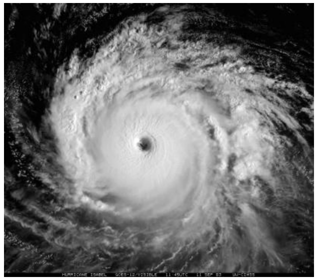
[Courtesy of Julio Bacmeister]

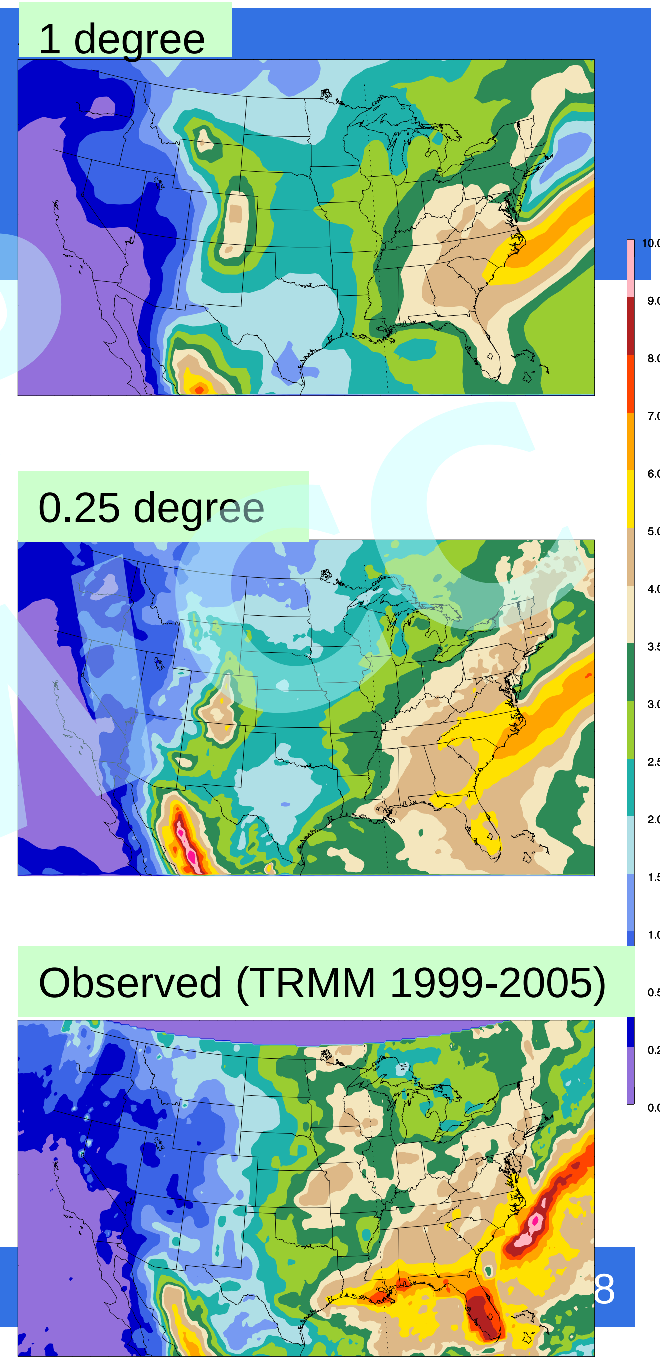


Regional

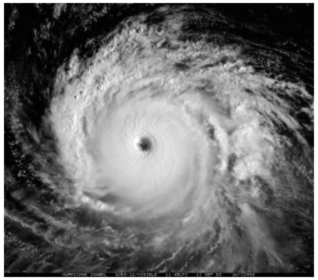
North America - JJA

But …. No improvement in summer precipitation in central US at 0.25°

Nocturnal maximum still completely missing



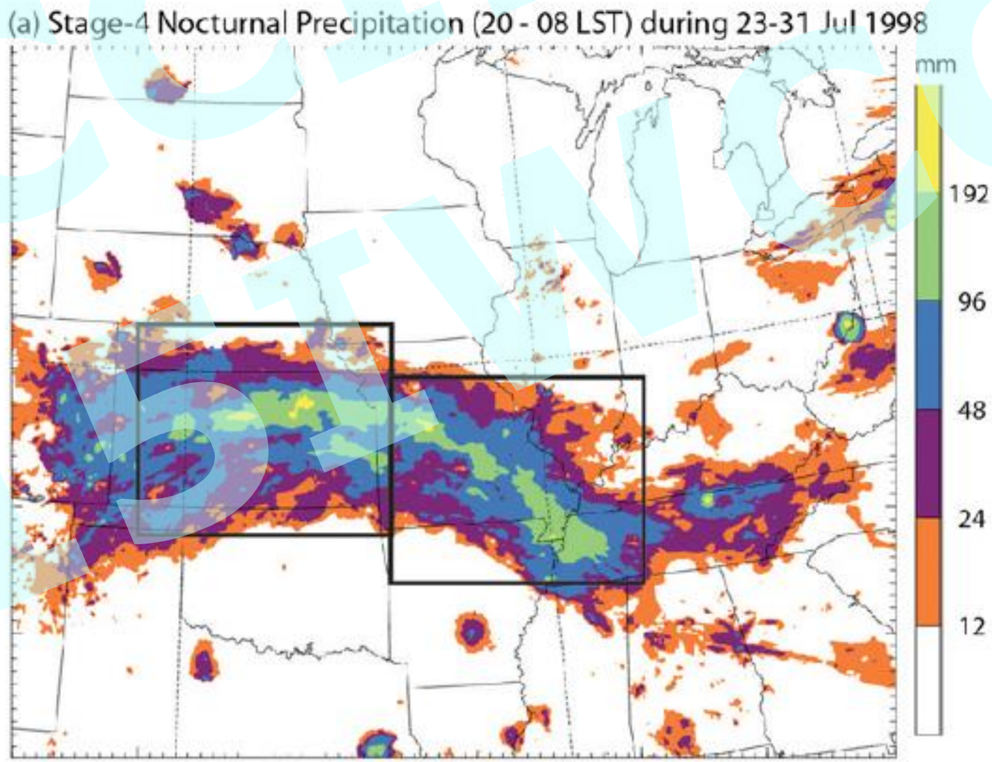
[Courtesy of Julio Bacmeister]



“Corridor” Event

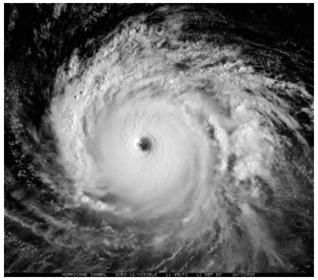
Nocturnal precipitation (8PM-8AM LST) July 23-31 1998

- Exit region of strong low-level jet
- Anomalous shear sfc-~2-5 km ➔Westerlies at 600 hPa
- Shallow stationary surface front to the south
- 68% of MCSs 1998-2002 associated with corridors



[Trier et al. 2014, JAS]

TCCIP 2015 TWRC

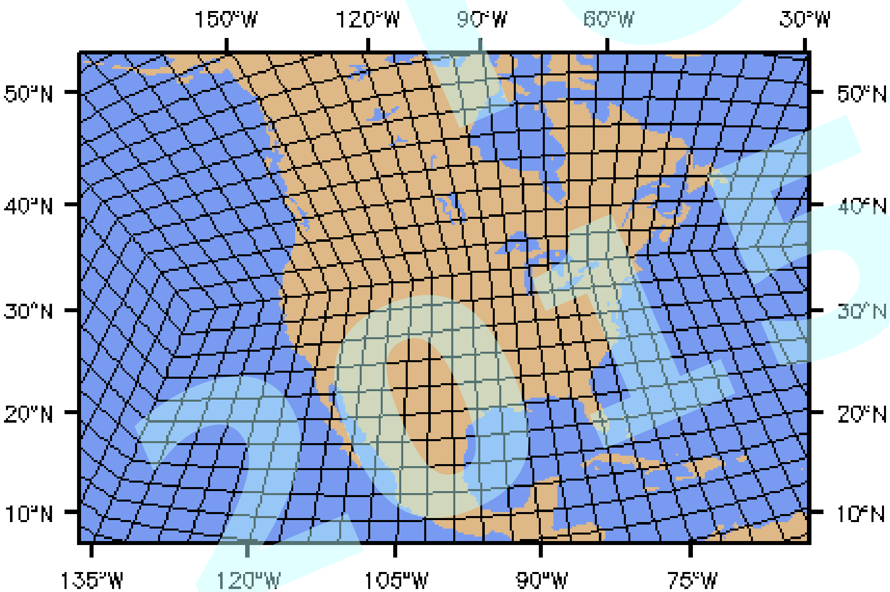


Investigate MSCs

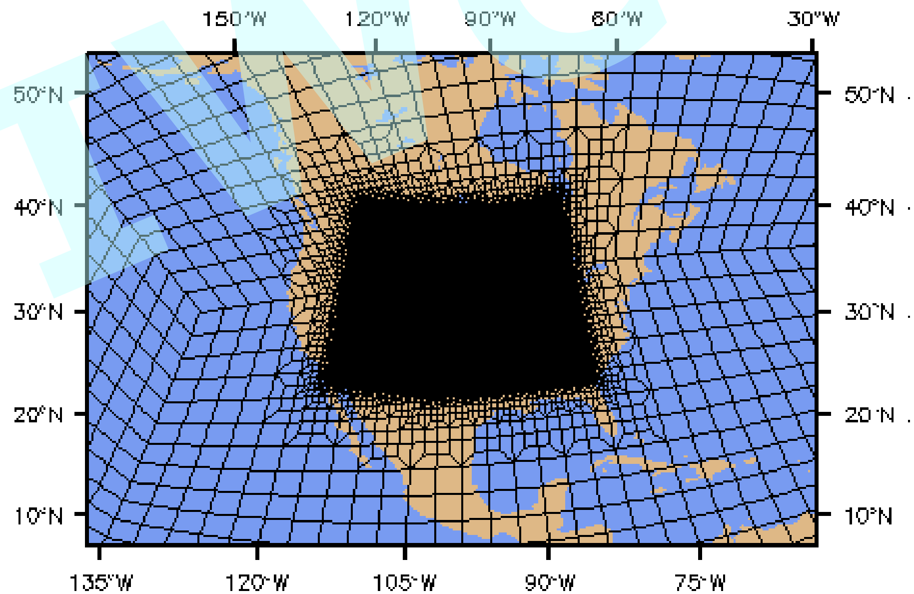
Why can’t CAM simulate midwest precipitation?

- Insufficient resolution?
- Physics errors?

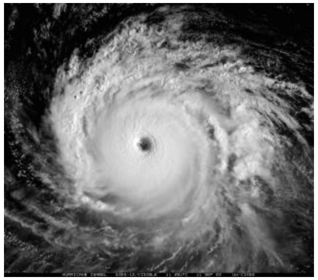
Uniform 100km(ne30)



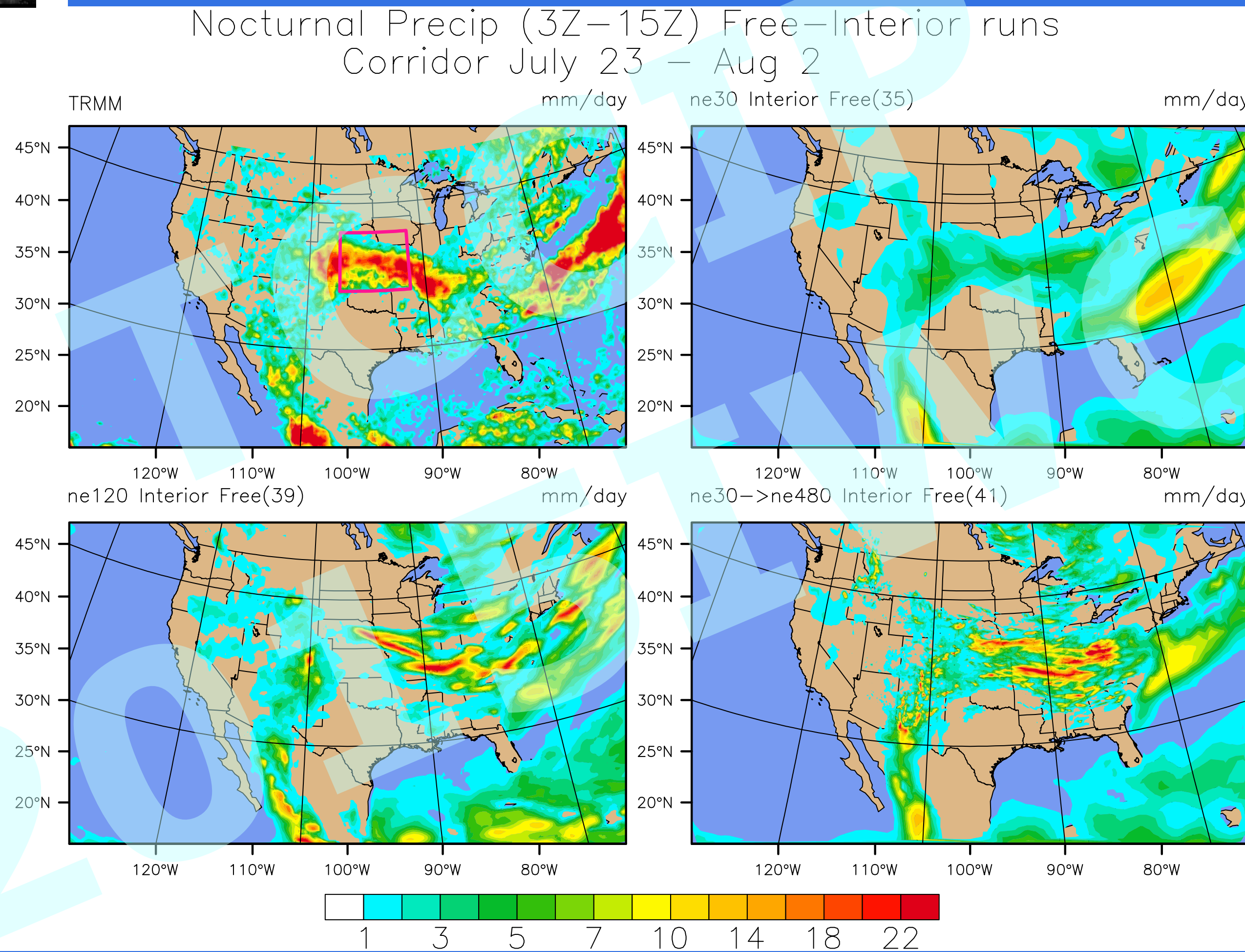
100km(ne30)➔6km(ne480)



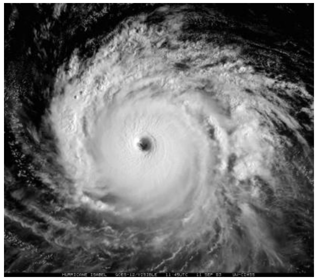
 [Courtesy of Julio Bacmeister]



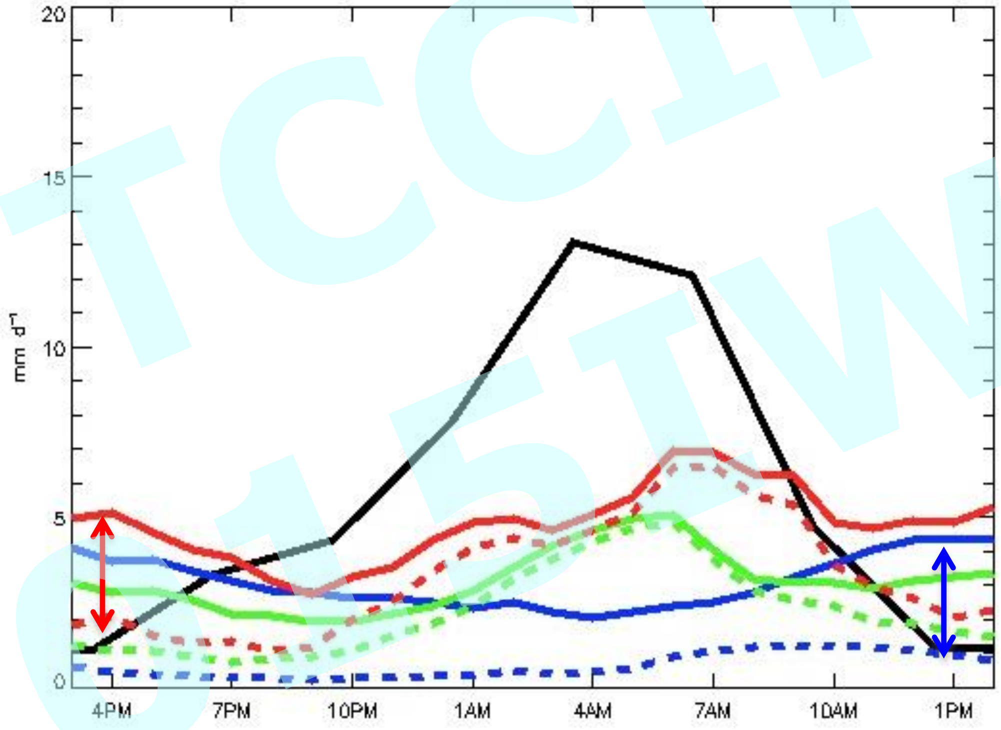
“Corridor” Event



[Courtesy of Julio Bacmeister]



Diurnal Cycle

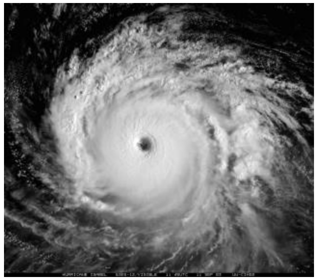


TRMM
100km
25km
6km

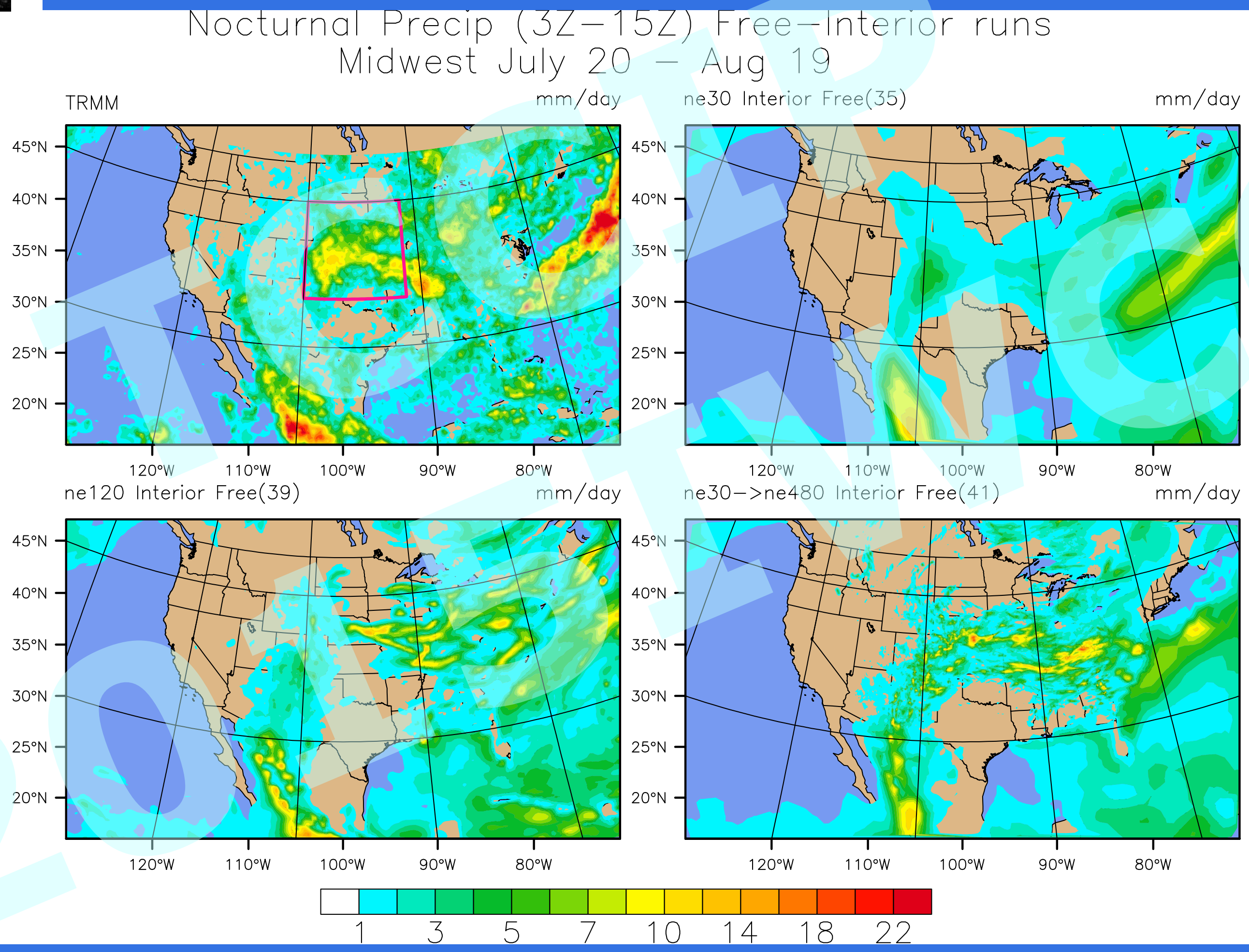
Difference is contribution from deep+shallow convection schemes

Solid lines – Total precip.
Dashed -- Large-scale

TCCIP 2015WCC

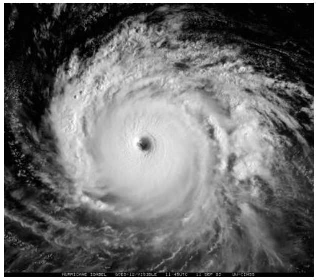


Midwest Precip

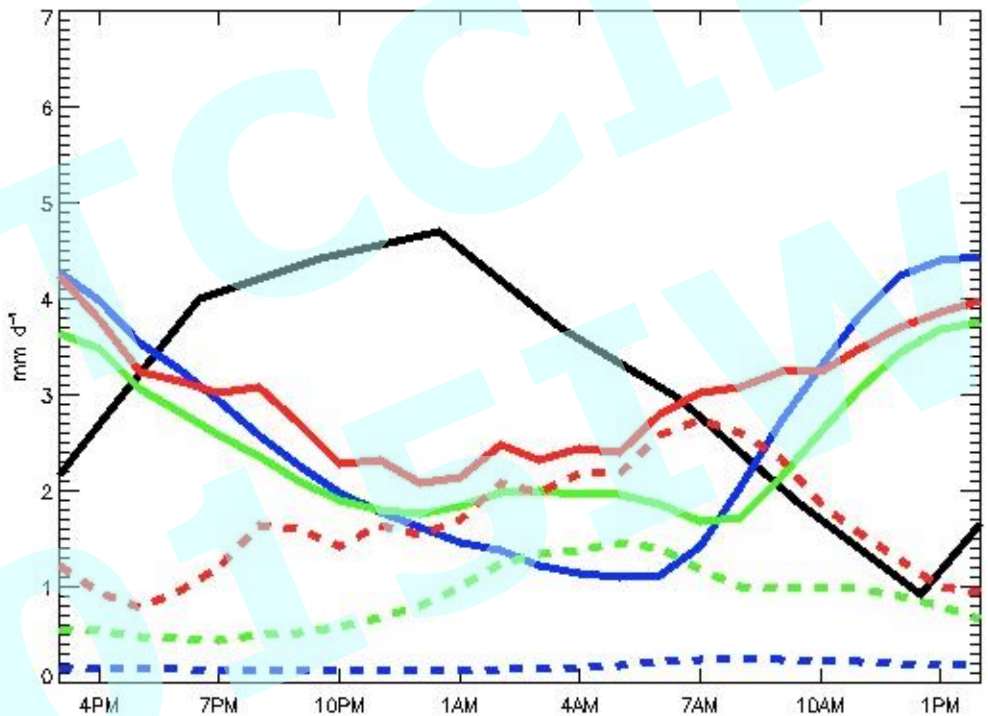


2015 TIGC

[Courtesy of Julio Bacmeister]



Midwest Precip

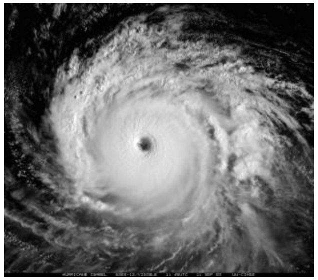


TRMM
100km
25km
6km

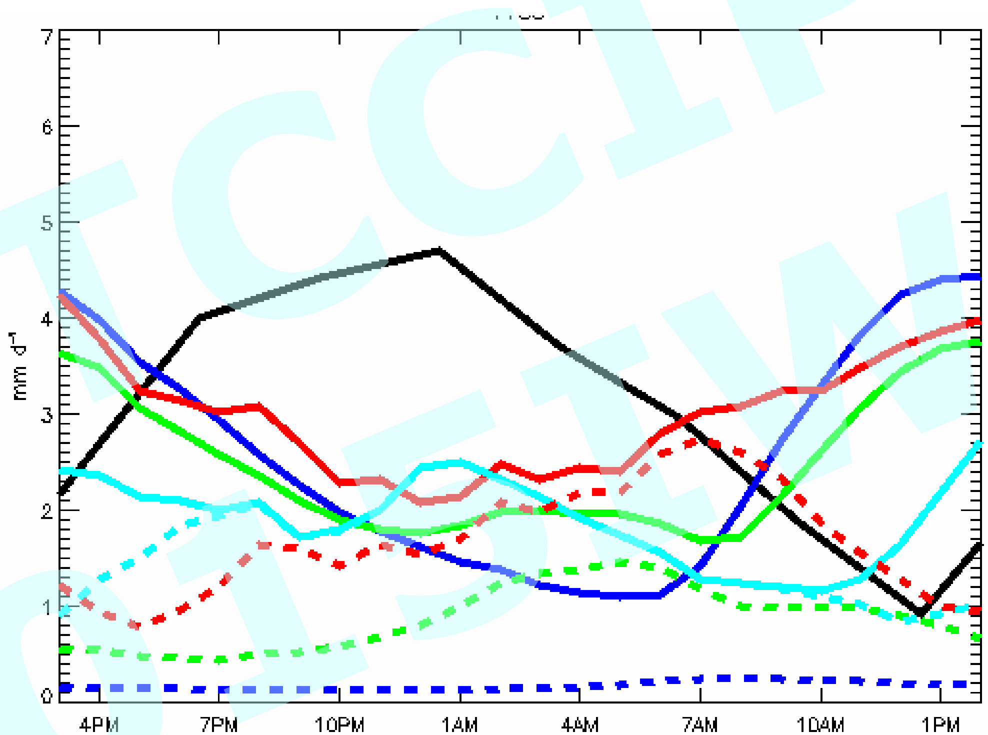
Solid lines – Total precip.
Dashed -- Large-scale

Difference is contribution from deep+shallow convection schemes

TCCIP 2015 NCC



Midwest Precip



TRMM

100km

25km

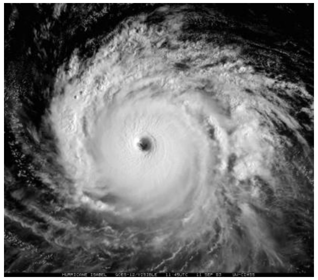
6km

6km no-deep scheme

Difference is contribution from deep+shallow convection schemes

Solid lines – Total precip.
Dashed -- Large-scale

TCCIP 2015 NCC

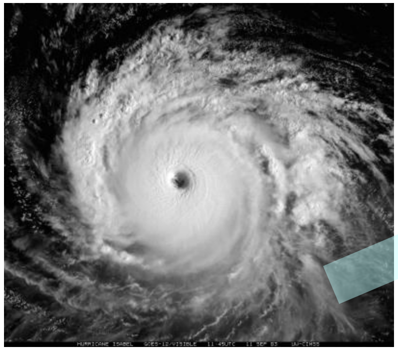


Brief Recap

- Not everything is improved with resolution… surprise!
- Large-scale precipitation has approximately correct diurnal cycle, but parameterized convection is always nearly 180º out of phase.
- “Extreme” 1998 corridor event is reasonably well captured even at 25km.
- Parameterized convection plays a surprisingly large role in 6km simulations.

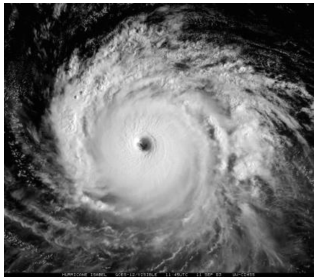
TCCIP 2015IWCC

[Courtesy of Julio Bacmeister]



Tropical Cyclones

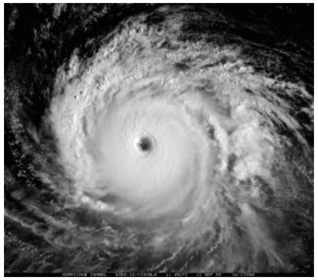
TCCIP
2015IWCC



Tropical Cyclones

- National Center for Atmospheric Research and Dept. of Energy supported CAM has shown some *"skill"* in simulating extreme weather events, especially at higher horizontal resolutions (~25 km).
- This was shown with idealized tests of TCs in previous versions of CAM and as well as decadal simulations with CAM5.
- However, there is still much room for improvement as there exist biases in intensity, track duration, regions of formation, etc.
- In addition, there is uncertainty in the tuning of the model at these high horizontal resolutions and its impact on extremes.

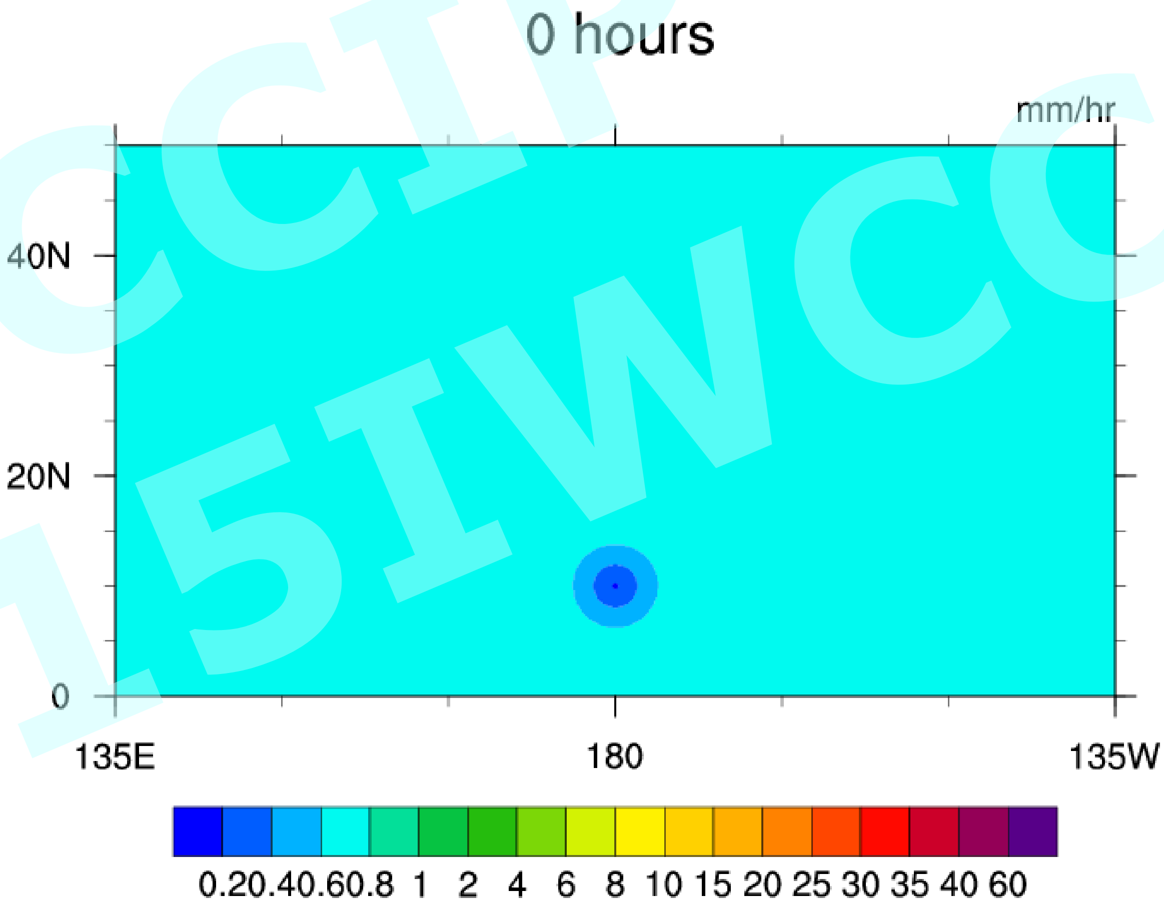
TCCIP 2015IWCC



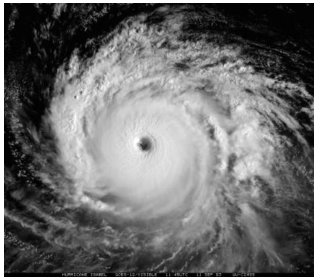
Idealized Simulations

Total Precipitation
Rate
(mm/hr)

FV
$0.125^{o} \approx 14$ km

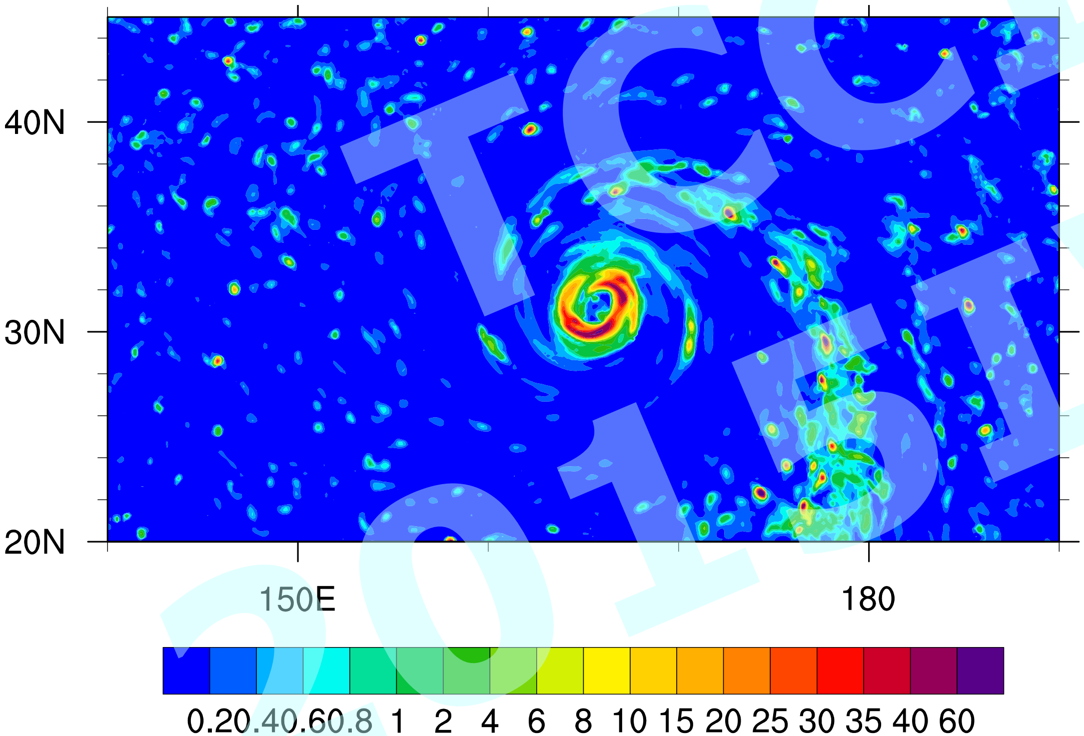


TCCIP 2015IWCC

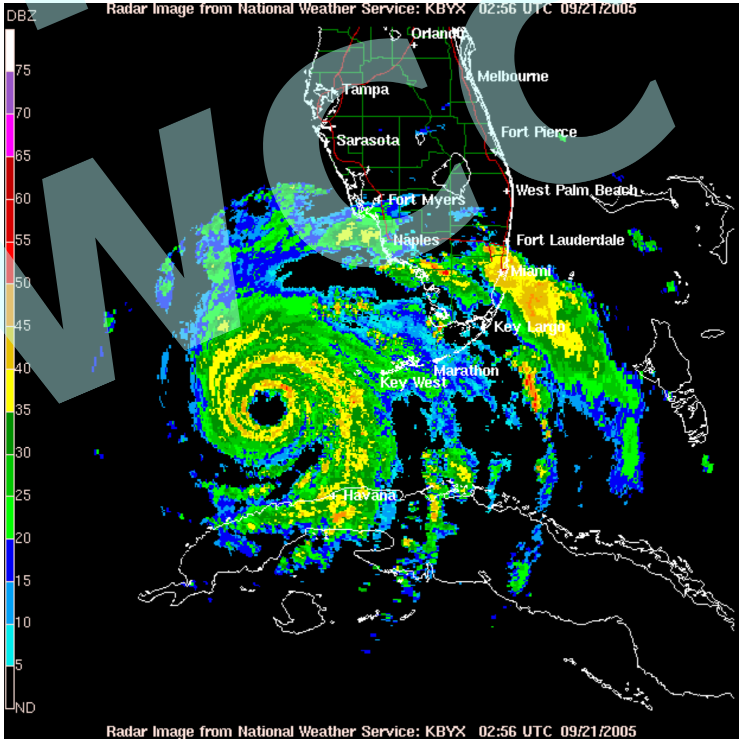


Intercomparison: Physical Realism

Total Precipitation Rate
FV Simulation (0.125° ≈ 14 km)

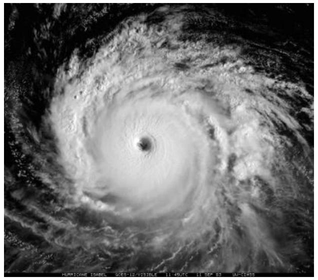


Radar Image of
Hurricane Rita (2005)



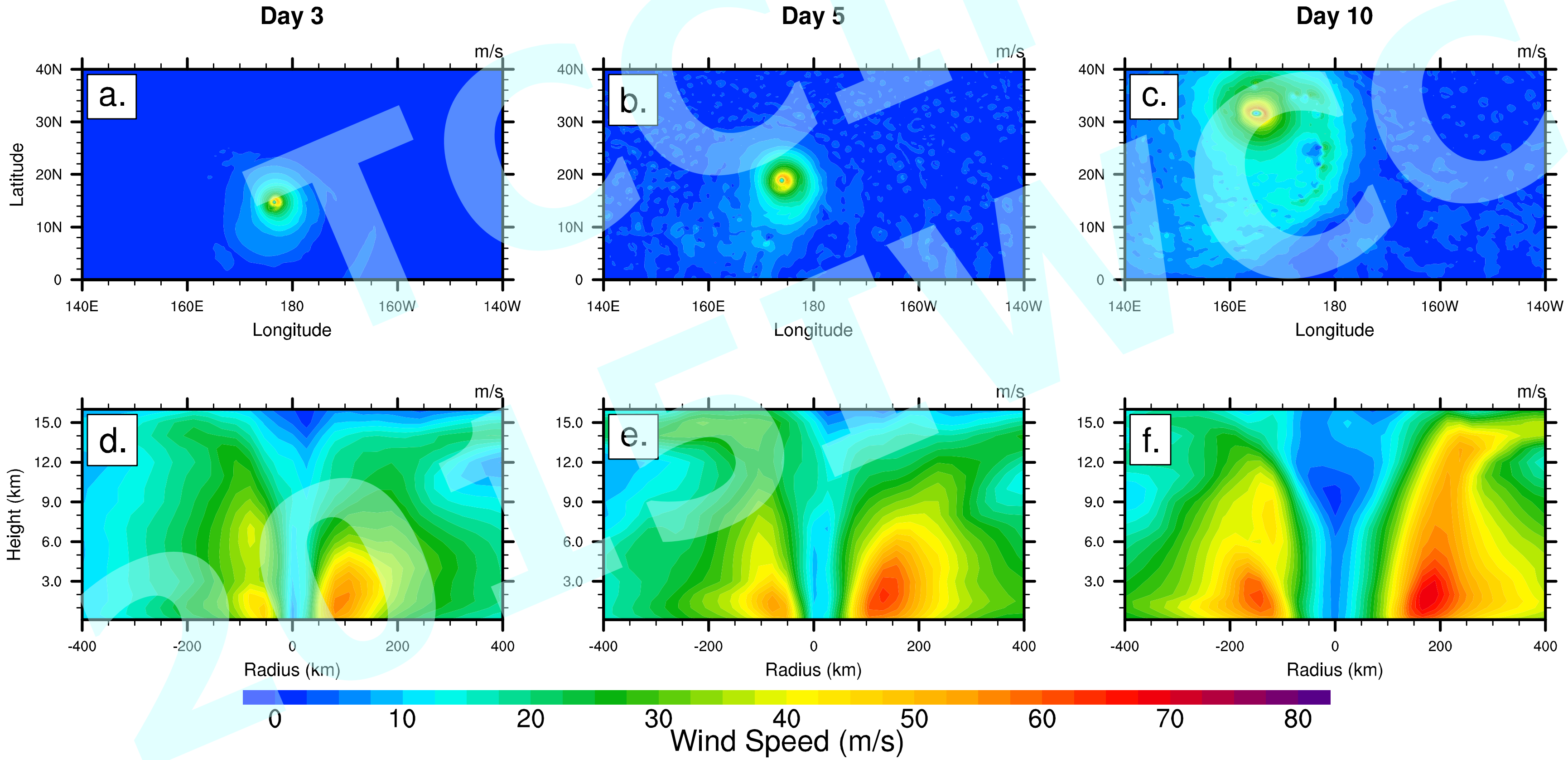
TCCIP 2015 IWCC

Radar image courtesy of NWS

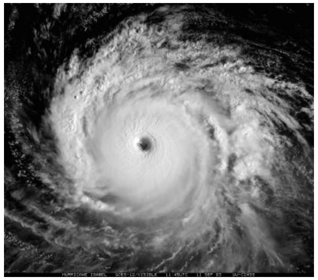


CAM 4

Wind Speed for 0.25° by 0.25° Simulation

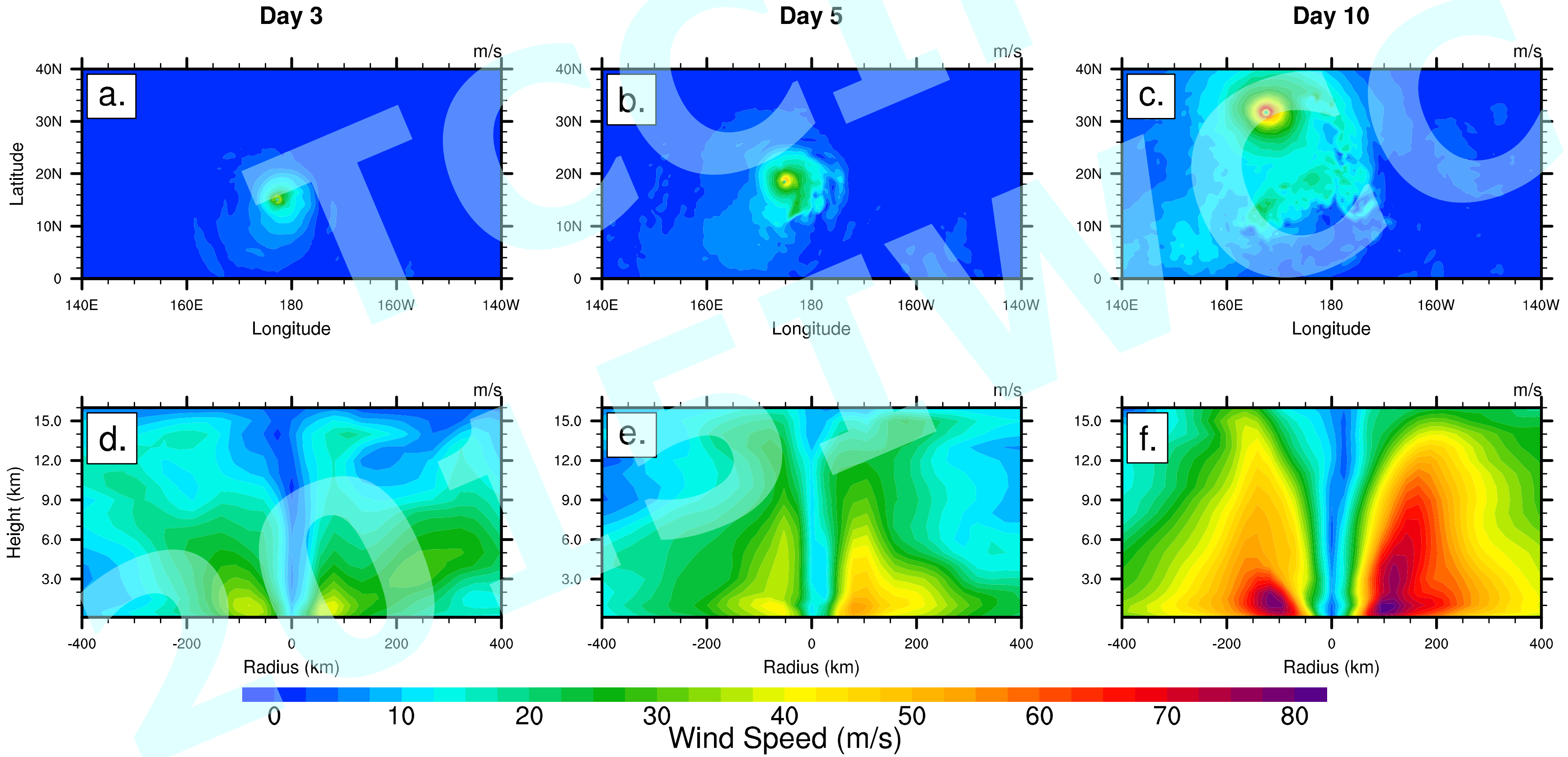


2015TCCIP-WC



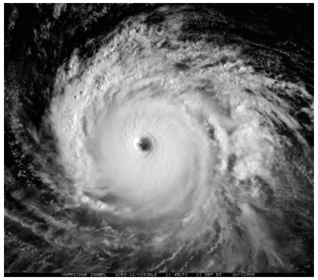
CAM 5

Wind Speed for 0.25^o by 0.25^o Simulation



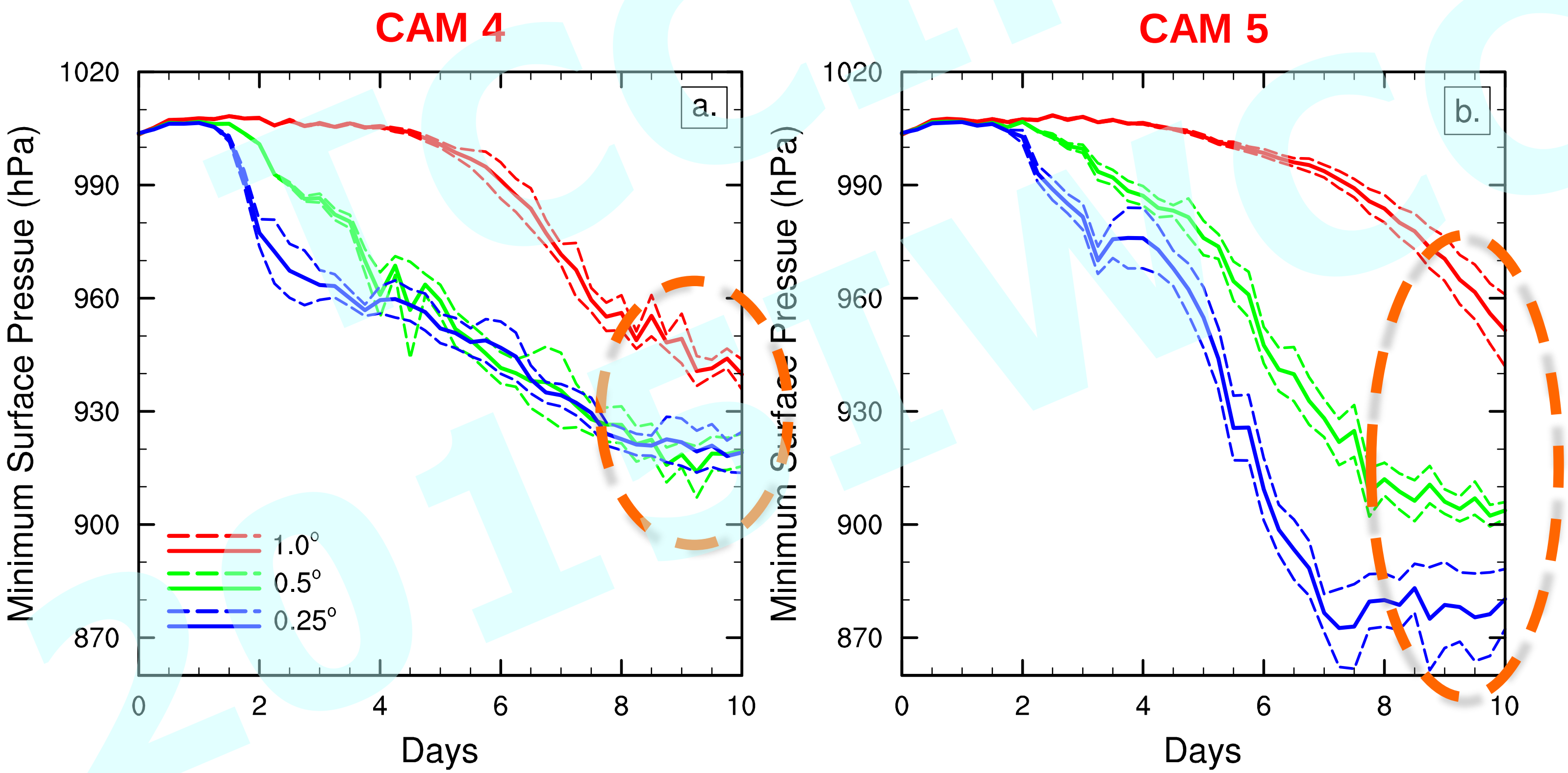
2015TCCIP-CWB

[Reed & Jablonowski 2011, JAMES]

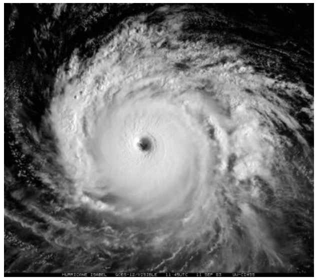


CAM 4 / CAM 5 Comparison

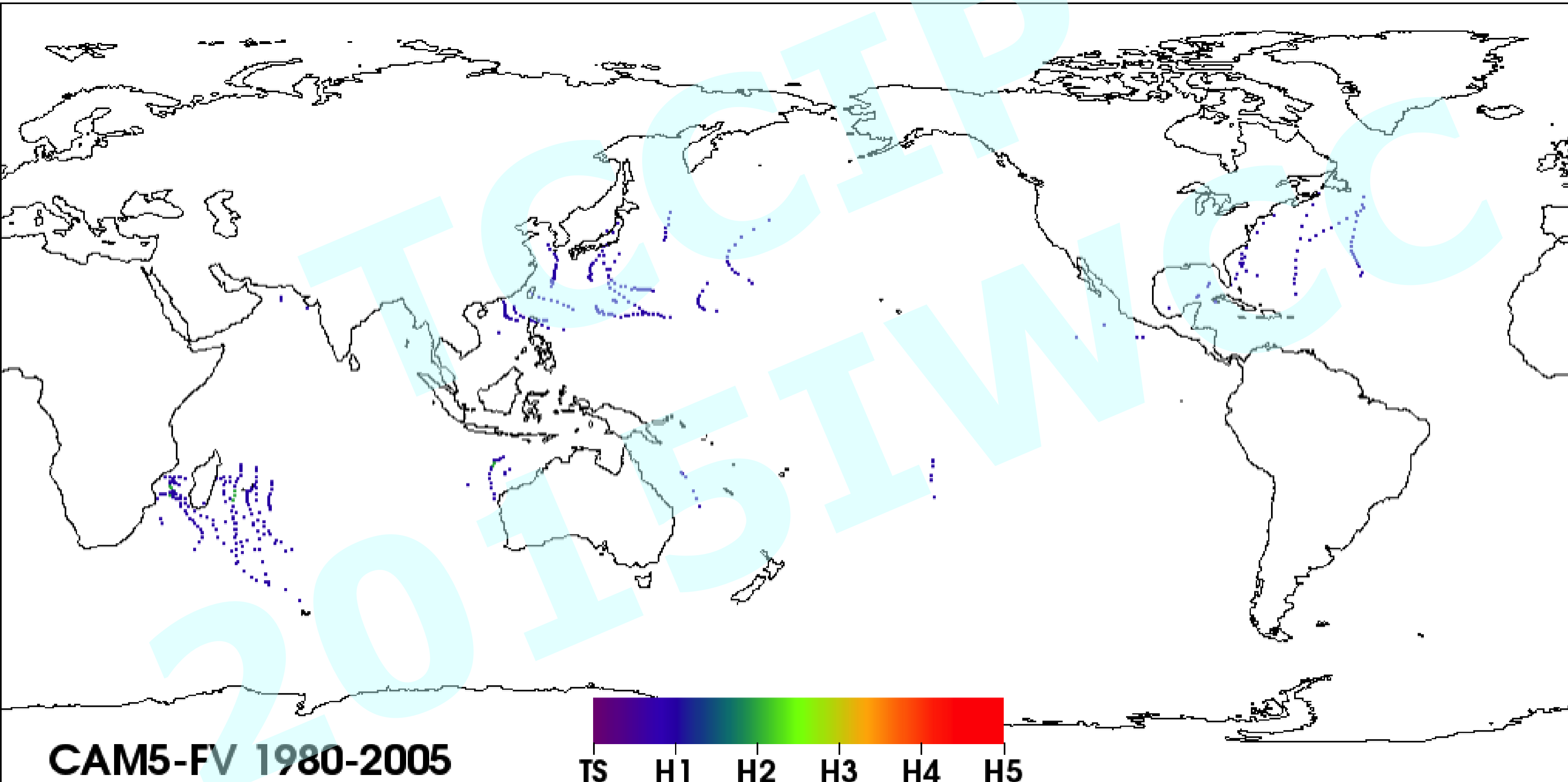
- Assess initial data and model uncertainties



2015 TCCIP WCC

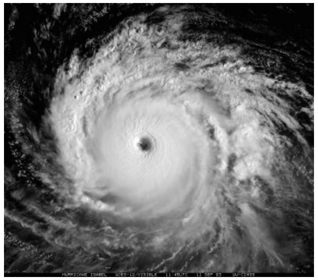


CAM5-FV 0.9° by 1.25° Storm Tracks - AMIP

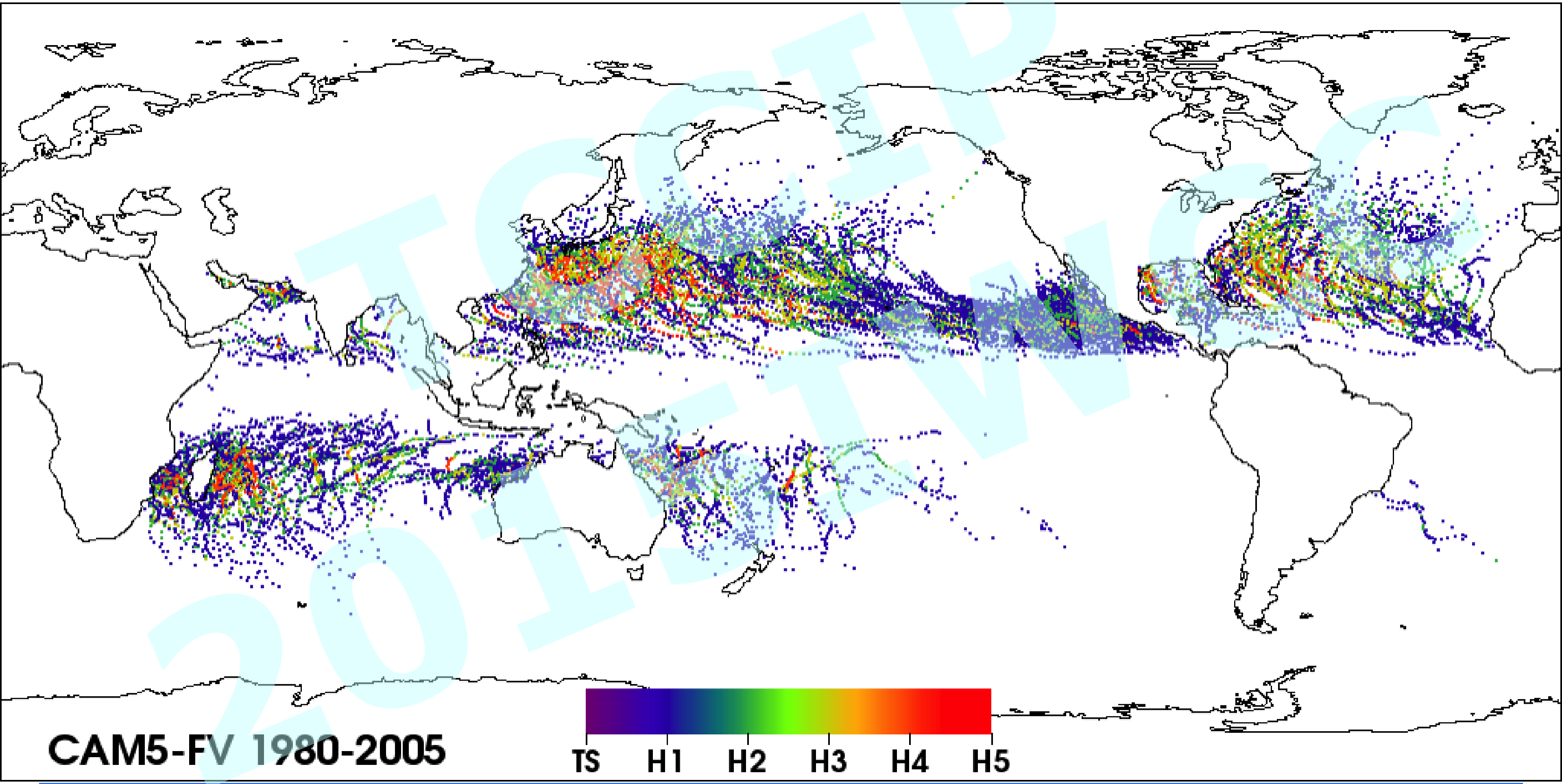


TCCIP
2015IWCC

[Wehner et al. 2014, JAMES]

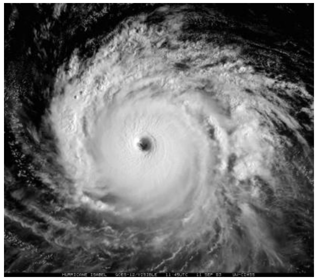


CAM5-FV 0.23° by 0.31° Storm Tracks - AMIP

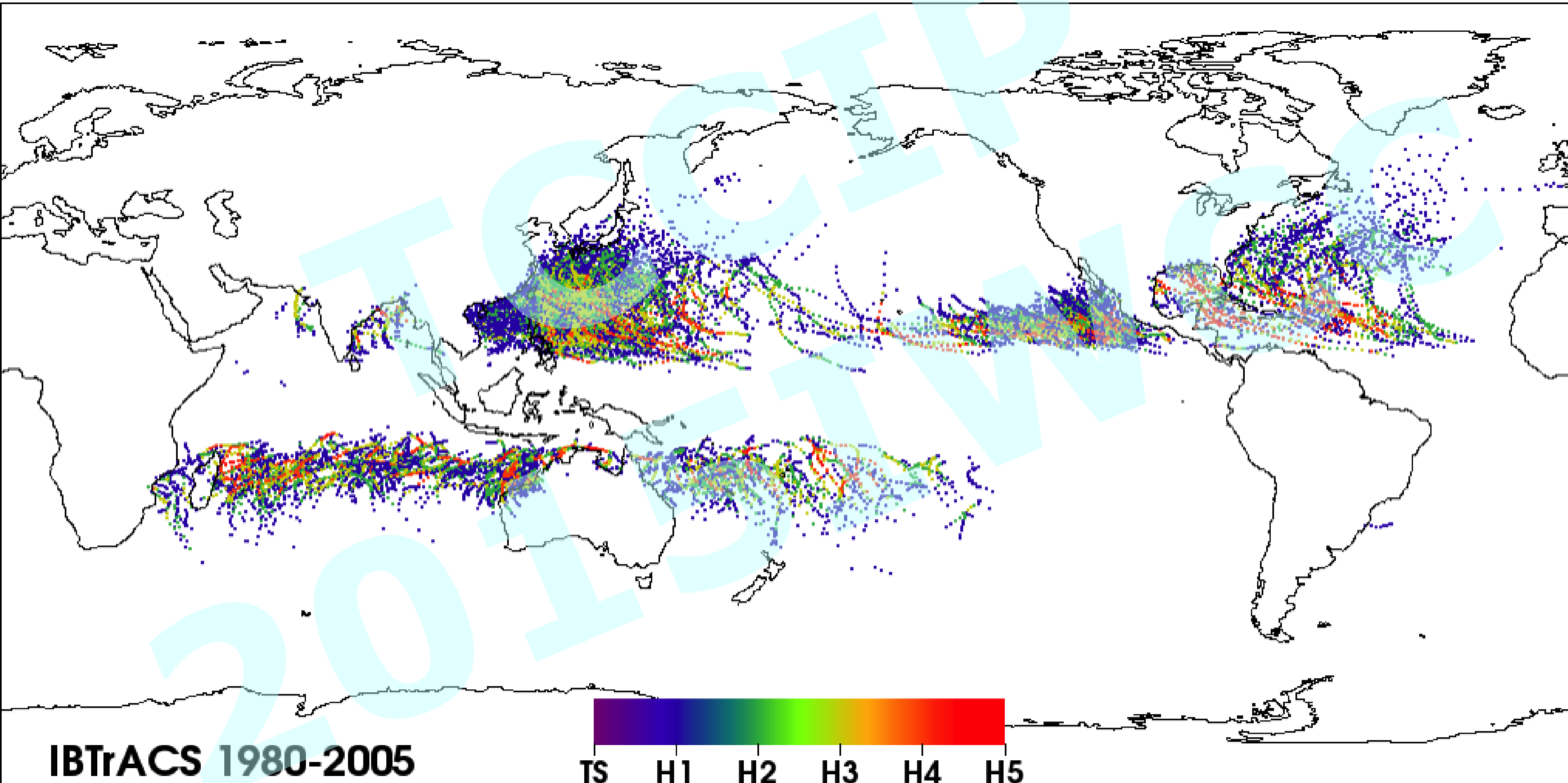


2015 TCCIP LSTWG

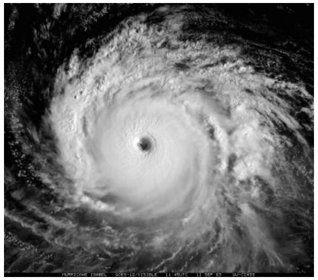
[Wehner et al. 2014, JAMES]



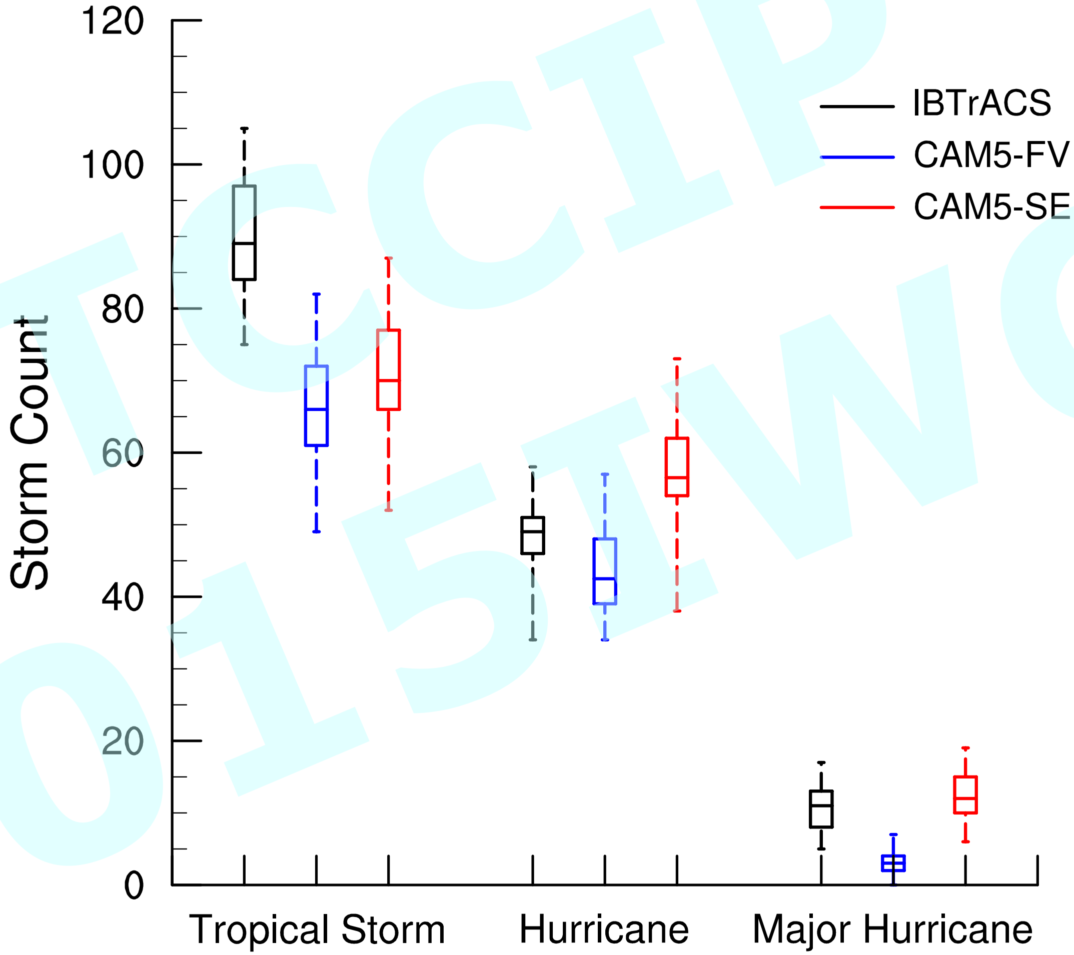
Observations



TCCIP
2015TWCC

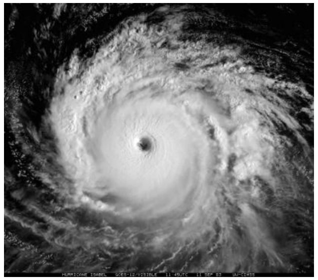


Dynamical Core Impact?

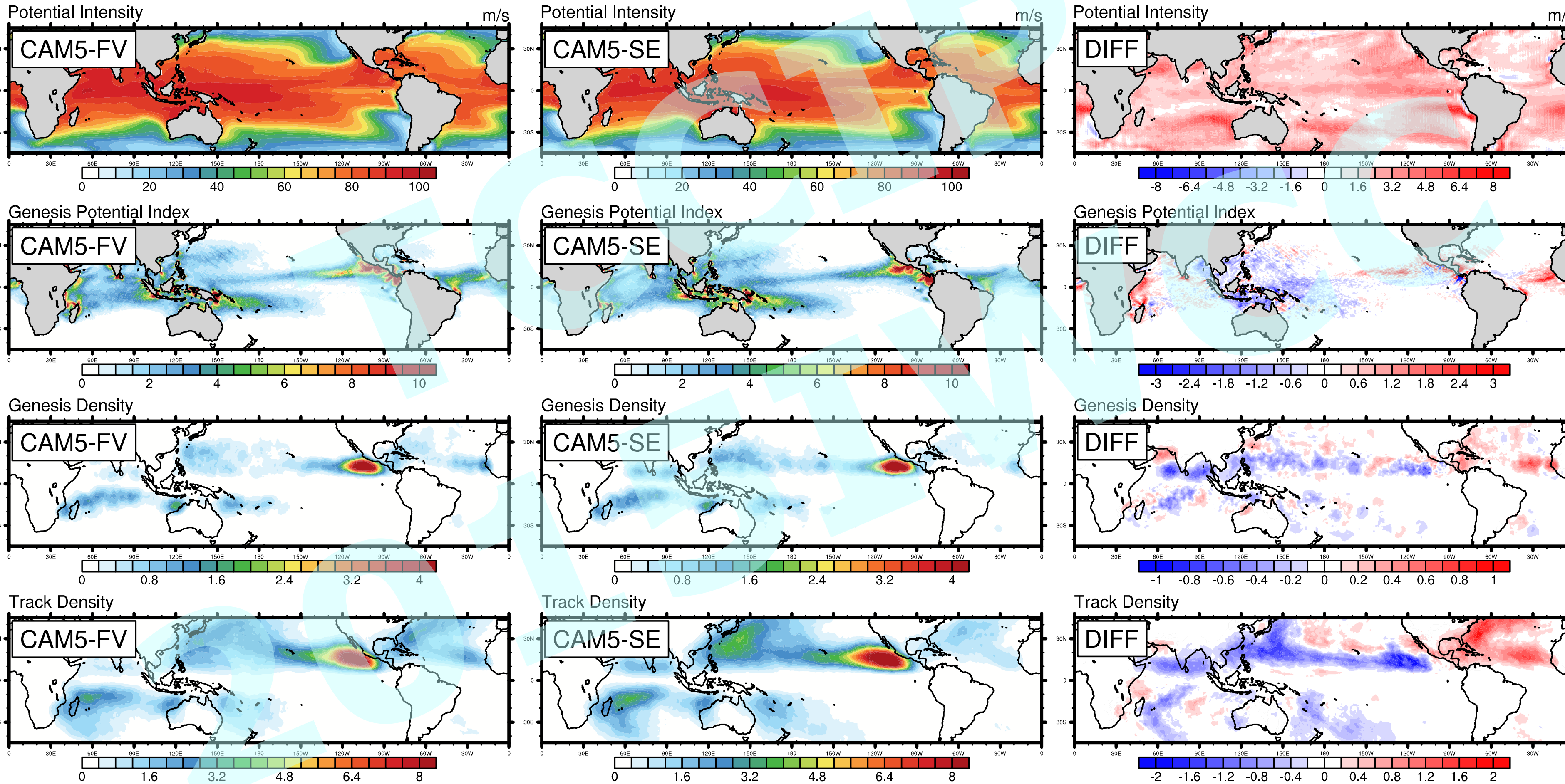


TCCIP 2015TWCC

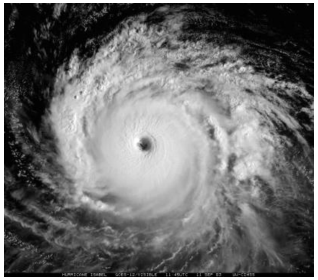
[Reed et al. 2015, *in prep*.]



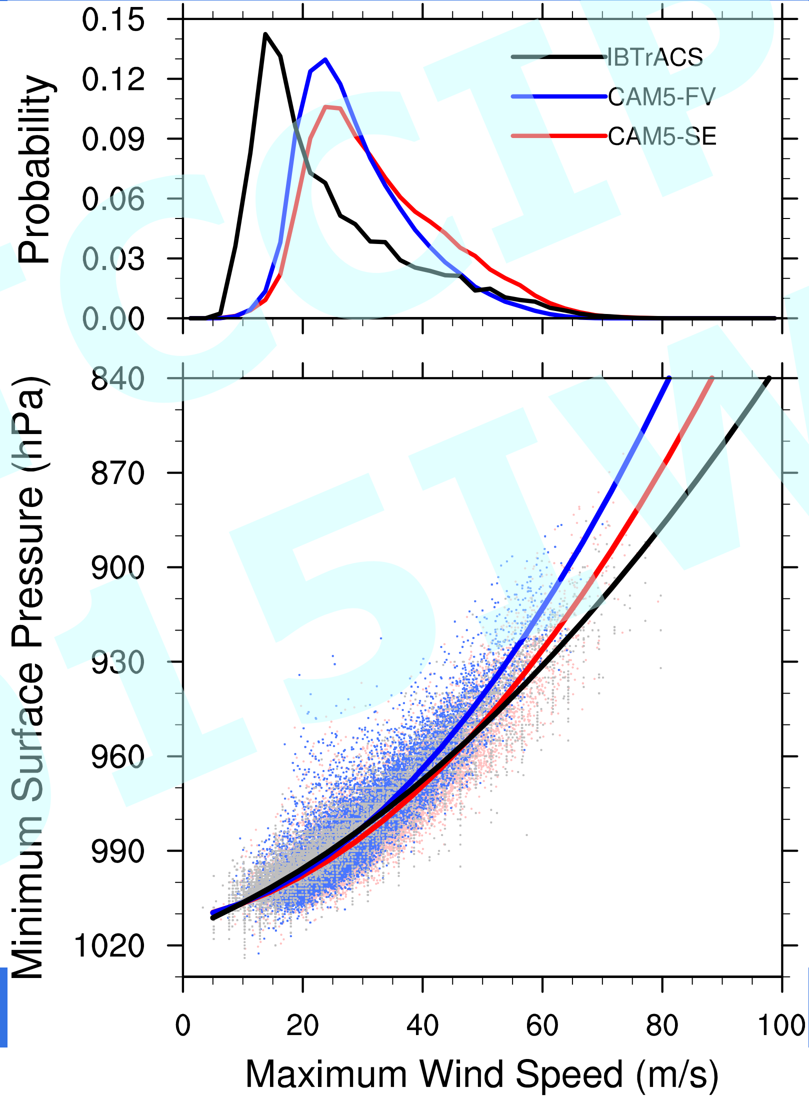
CAM5-SE Comparison: Previous CAM5-FV



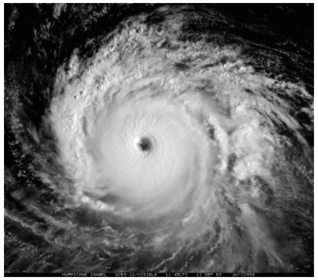
[Reed et al. 2015, *in prep*.]



Intensity Comparison

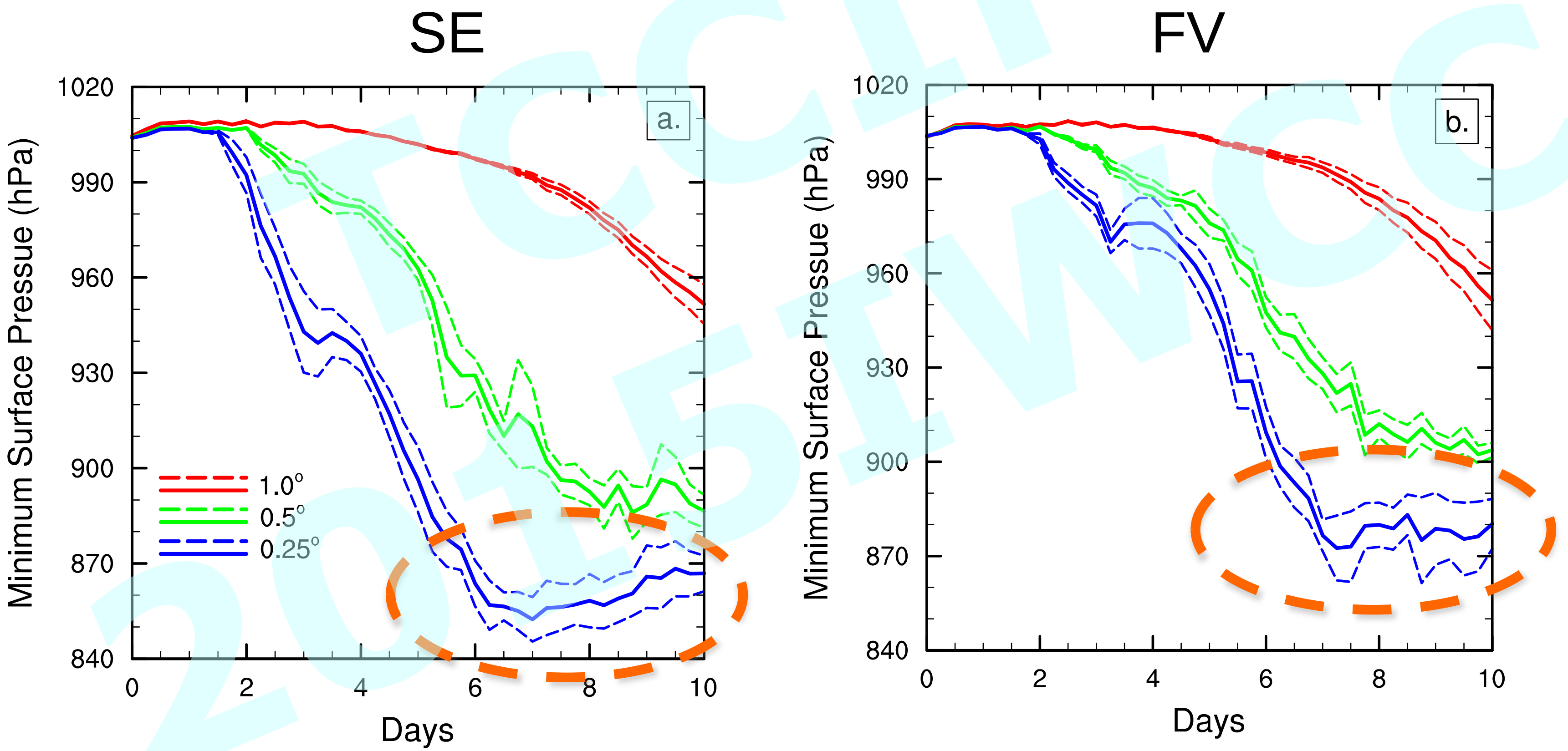


TCCIP 2015TWCC



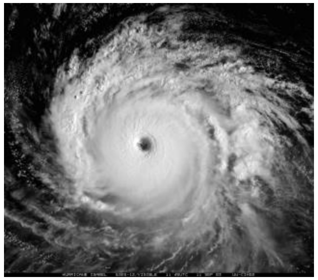
Think Back To Test Case

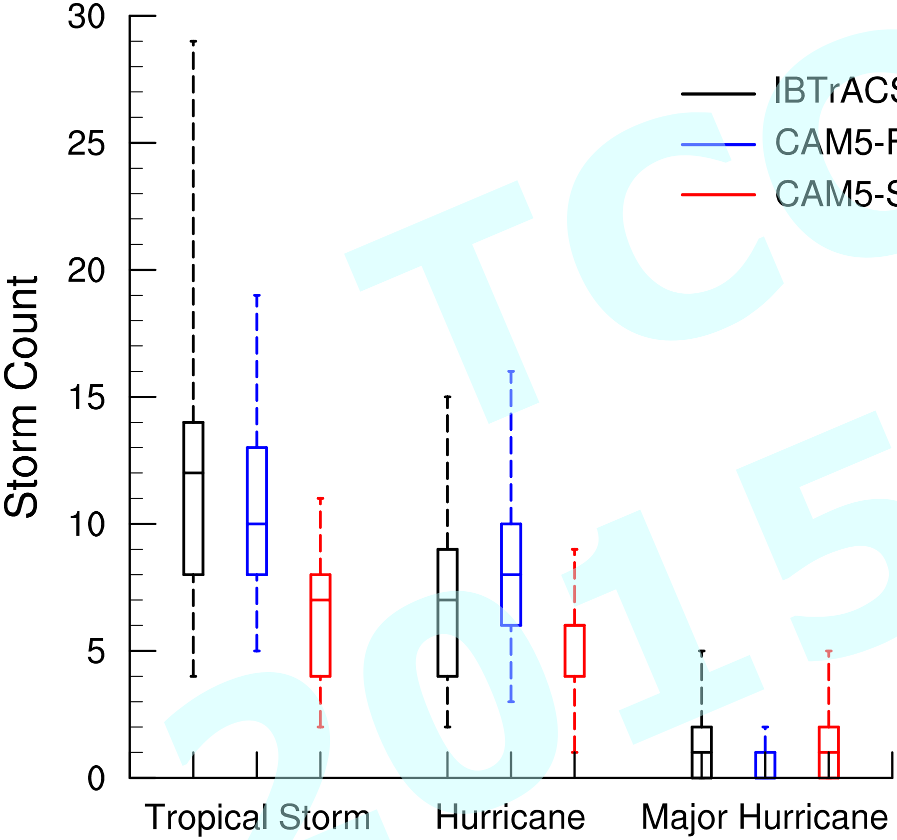
Minimum surface pressure, resolution dependence

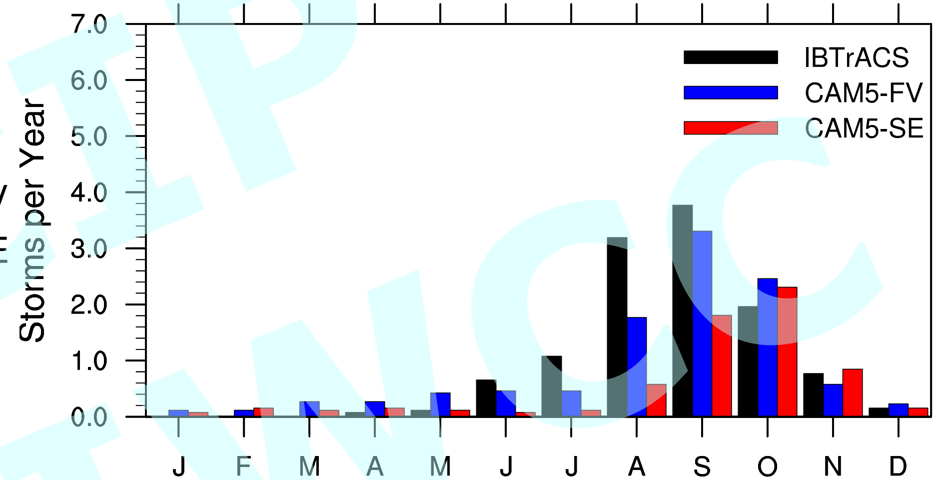


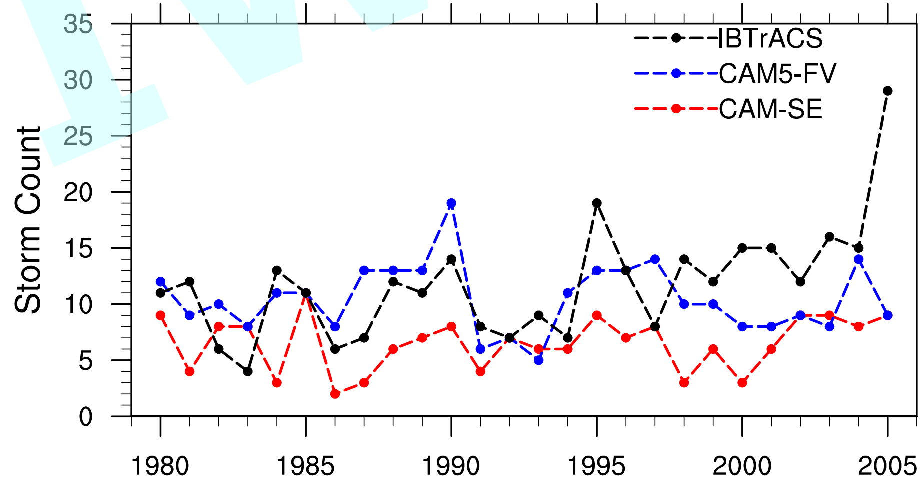
[Reed et al. 2012, ASL]

North Atlantic Basin

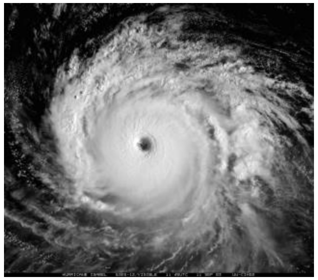




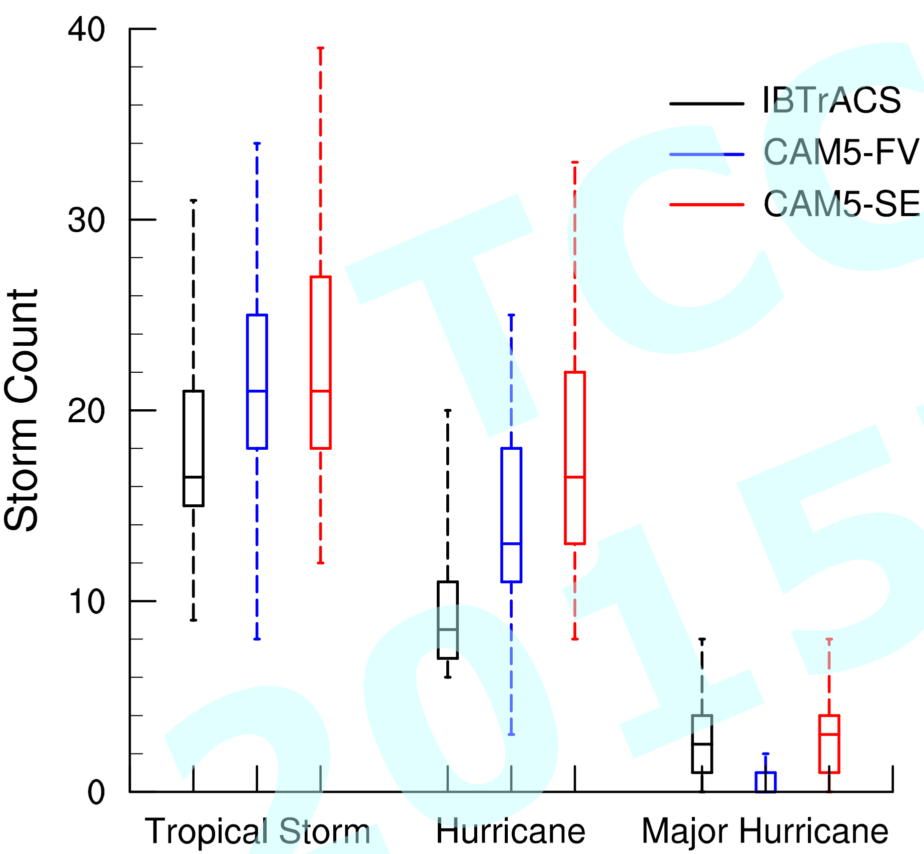


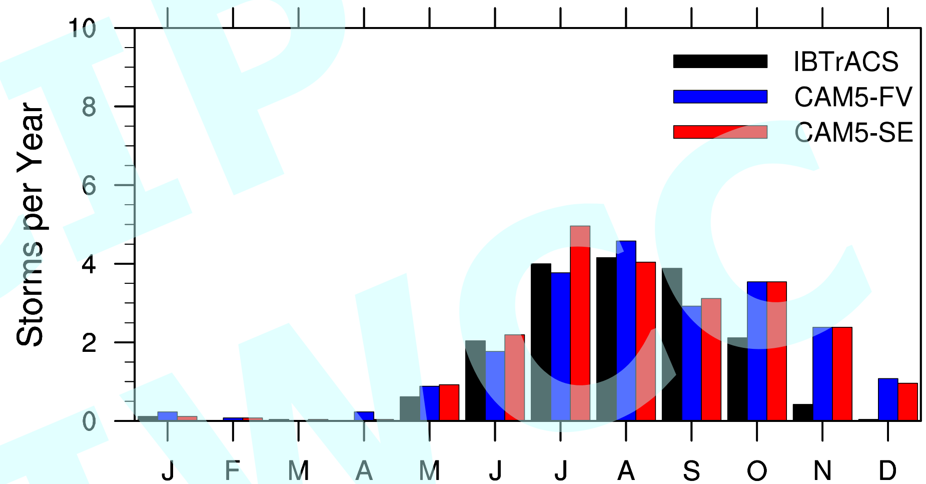


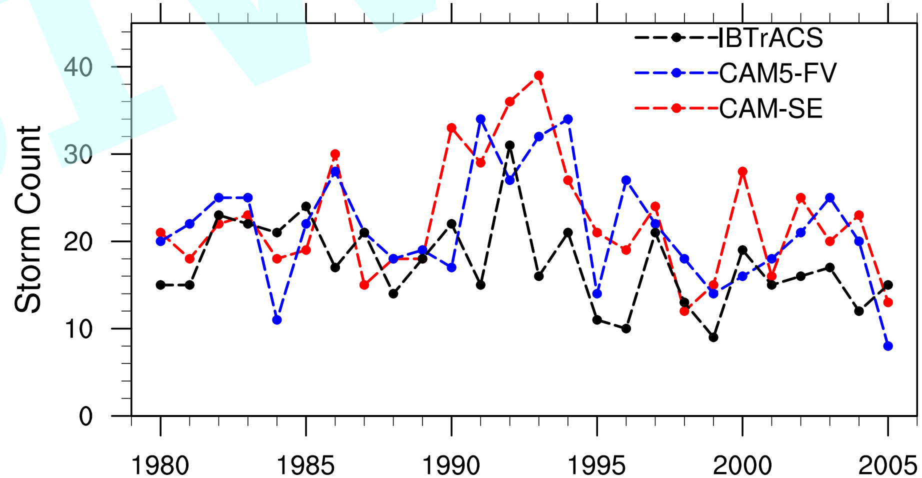
TCCIP 2015WC



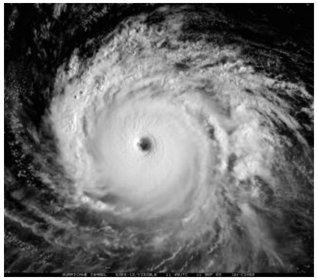
East Pacific Basin



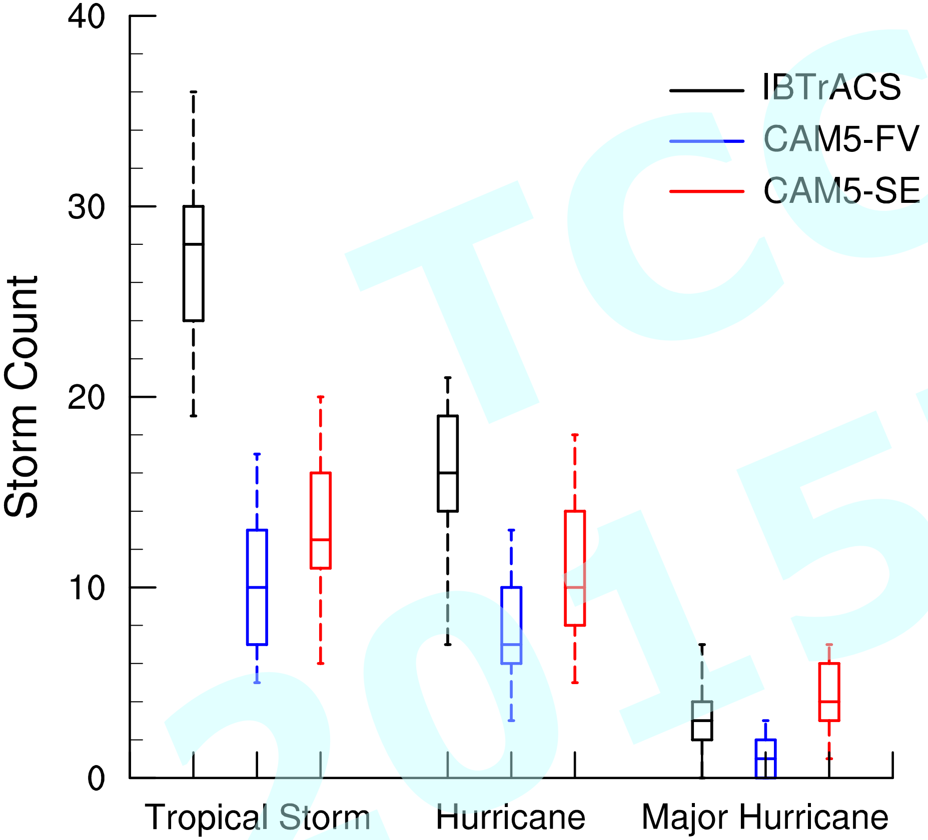


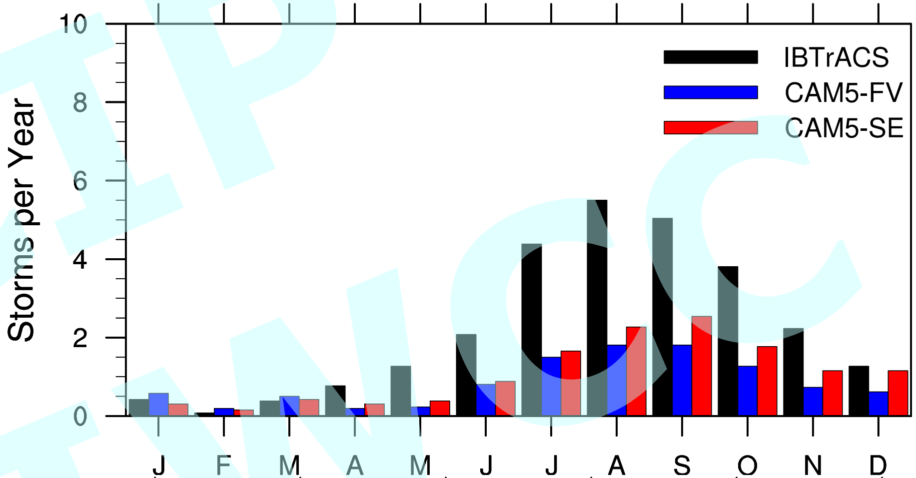


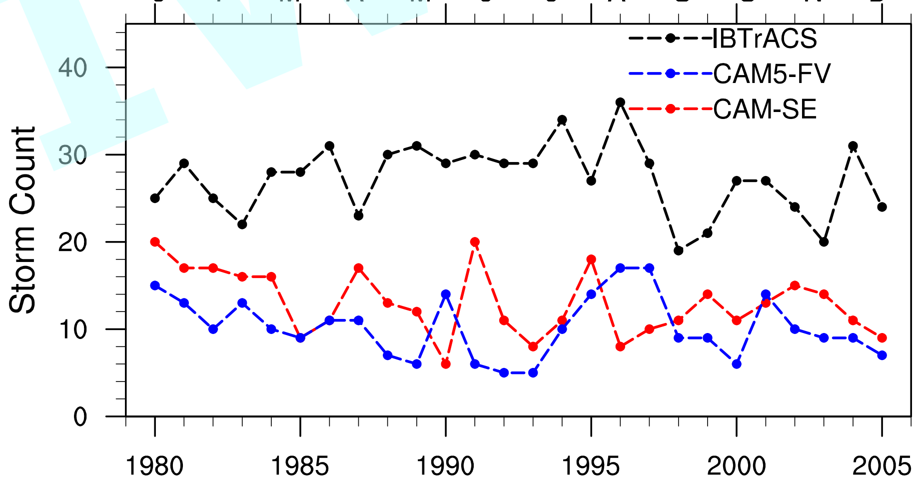
TCCIP
2015TWCC



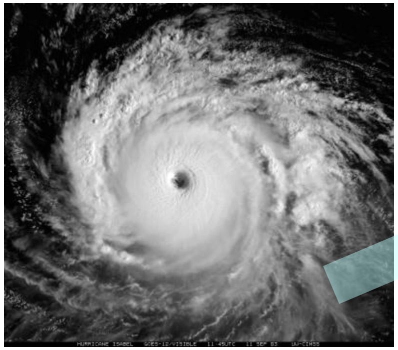
West Pacific Basin





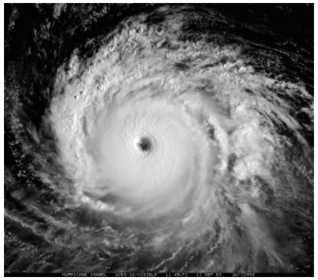


2015 TCCIP WC



Future Climate Simulations

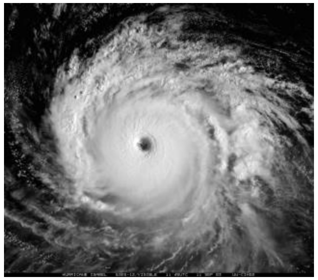
TCCIP 2015IWCC



Design of Experiments

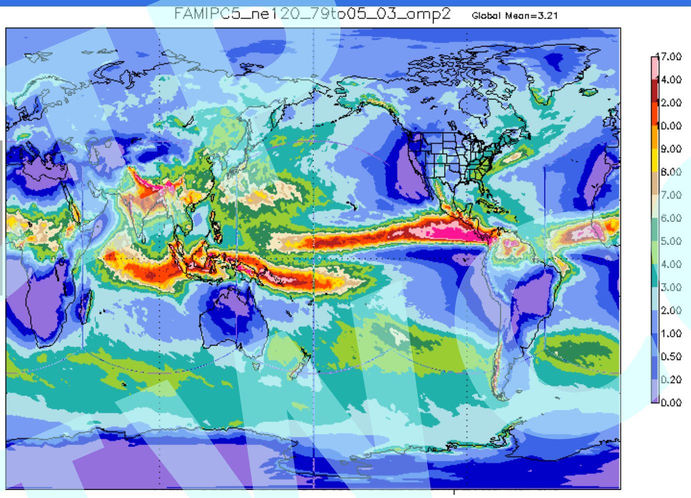
- National Center for Atmospheric Research's (NCAR) Community Atmosphere Model version 5 (CAM 5).
- The default Spectral Element SE dynamical core with 30 vertical levels is used at the horizontal resolution of ne120 (~25 km).
- Time-slice RCP 4.5 and RCP 8.5 scenarios for 2070-2089.
- Prescribed observed SSTs, ozone, CO_2, solar forcing, etc.
- GFDL tracking code is used for calculating all TC tracks.

TCCIP 2015IWCC

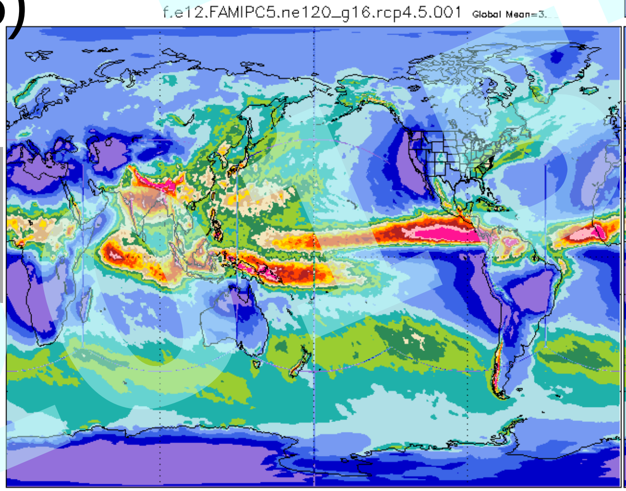


Precipitation

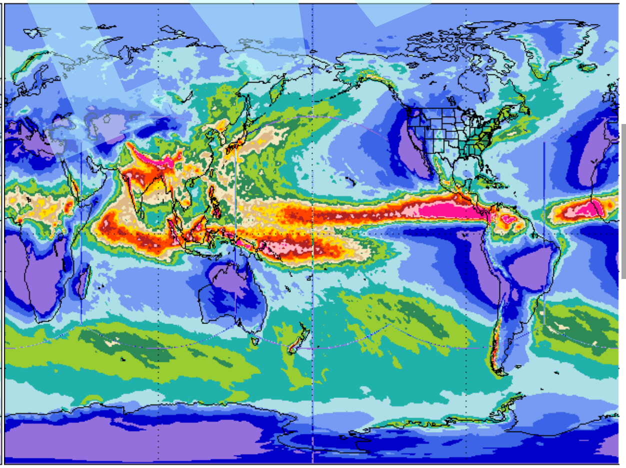
Precipitation
JJA
(2070-2075)
RCP4.5,8.5
and
(2000-2005)



Present day
2000-2005
Mean=3.21 mm d^{-1}

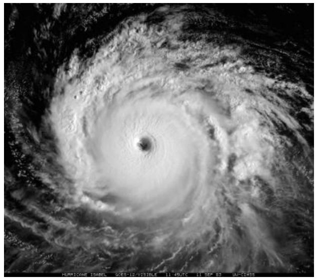


RCP4.5
2070-2075
Mean=3.35 mm d^{-1}



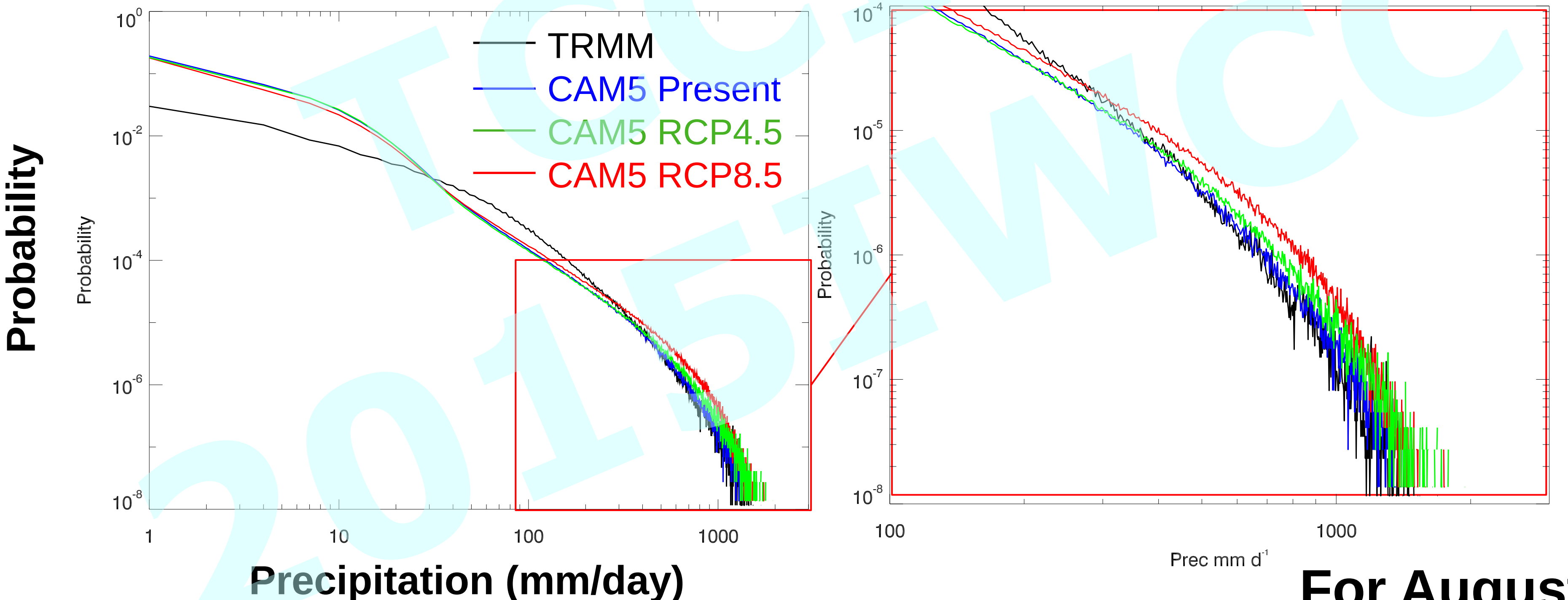
RCP8.5
2070-2075
Mean=3.40 mm d^{-1}

[Courtesy of Julio Bacmeister]



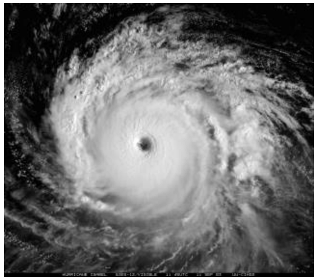
Extreme Precipitation – 25 km

Extreme precipitation is more intense in a warmer climate

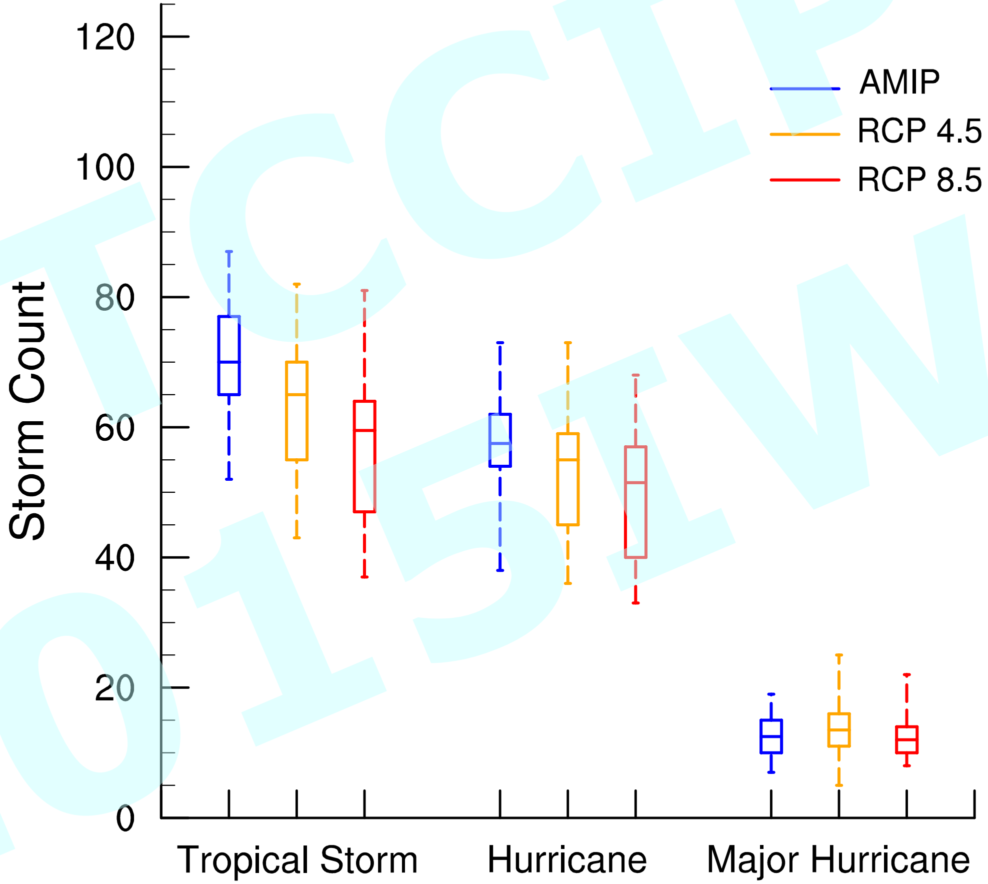


For August

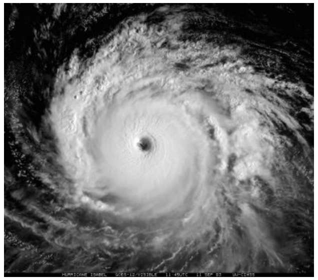
2015IWCC
TCCIP



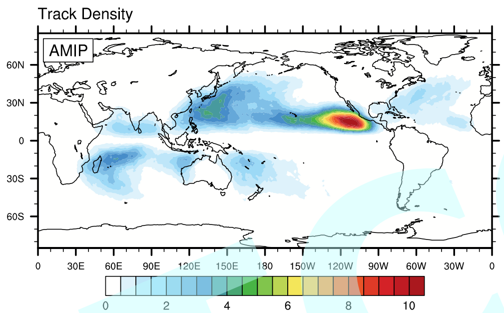
Future Climate Scenarios: Global Statistics

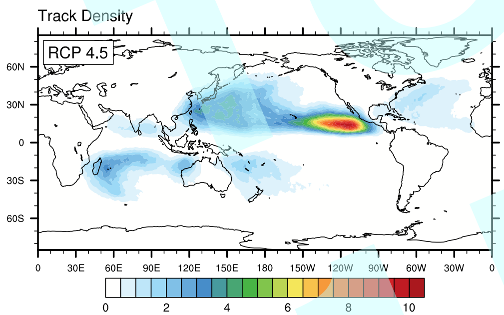


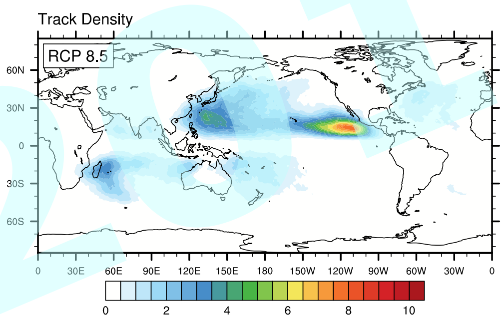
TCCIP 2015IWCC



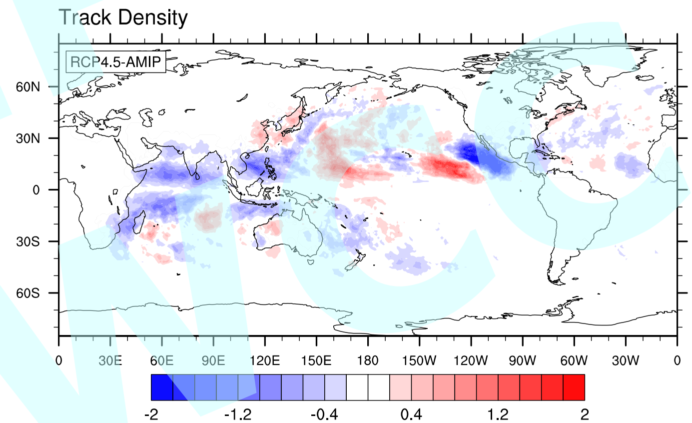
Future Climate Scenarios: Changes in Track Density

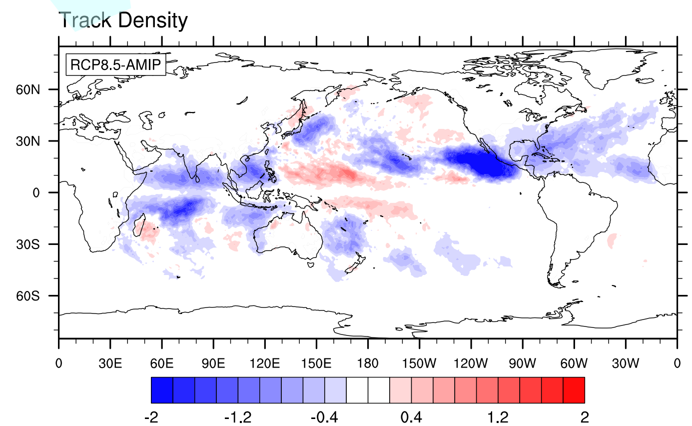


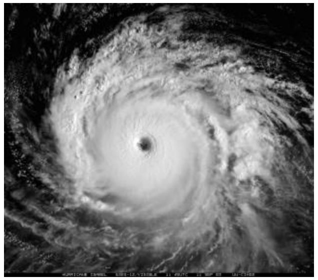




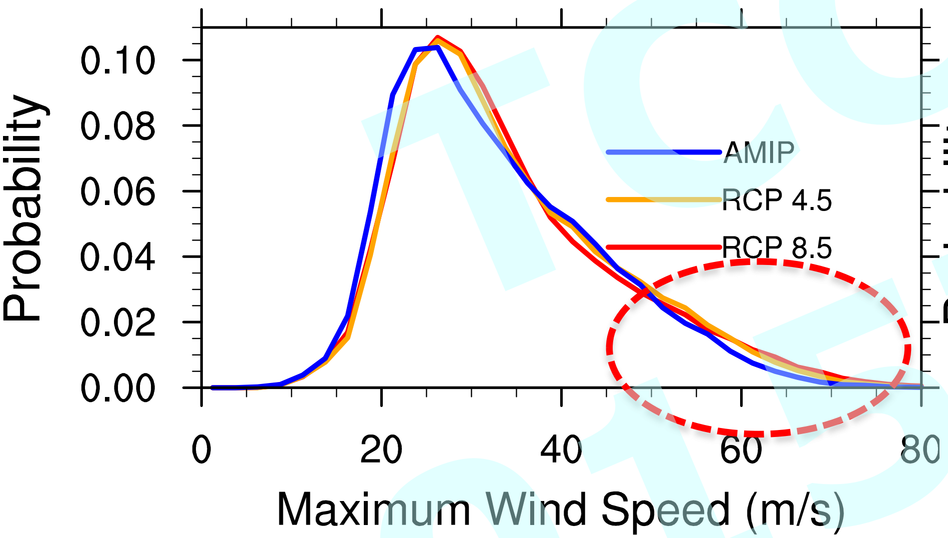
Difference From AMIP

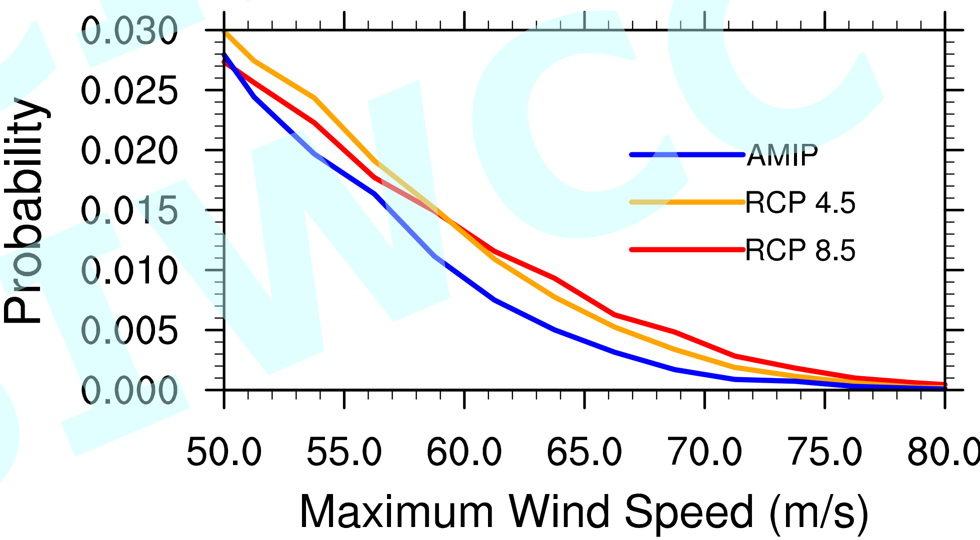




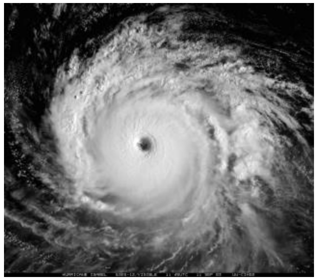


Future Climate Scenarios: Intensity Distribution



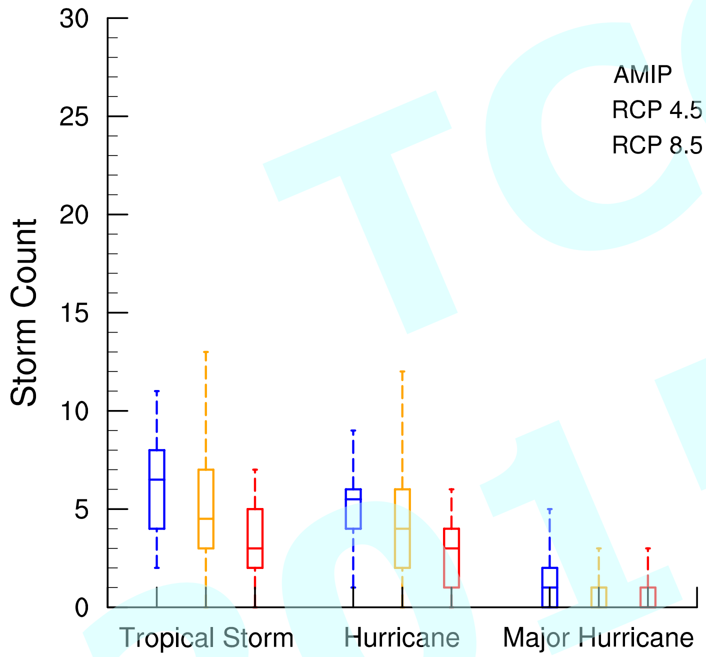


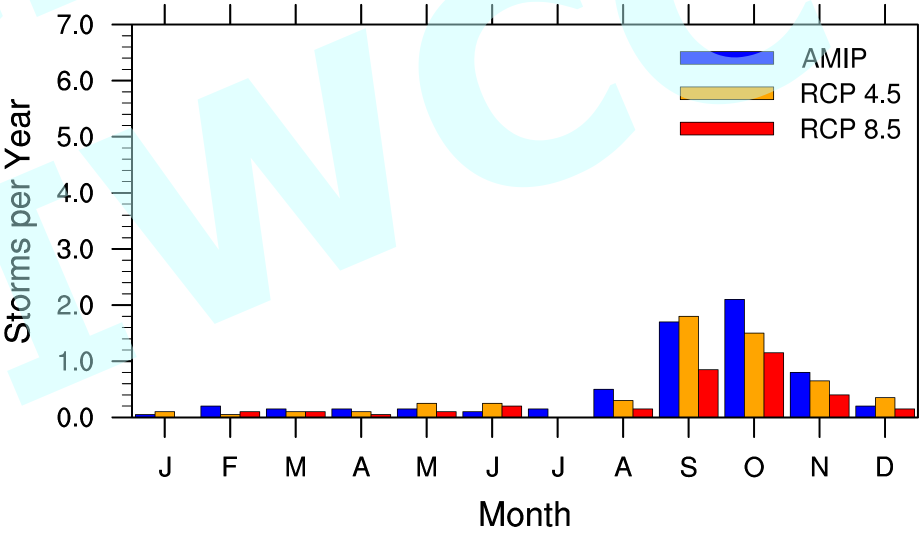
TCCIP 2015 WCC



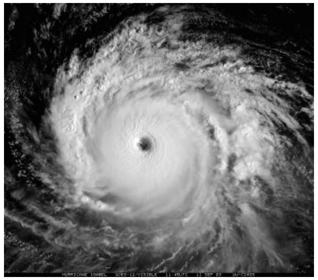
Future Climate Scenarios: Regional Differences

North Atlantic





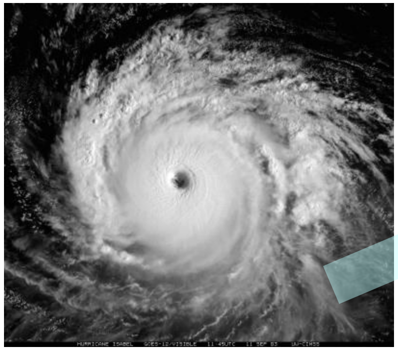
TCCIP 2015TWCC



Final Thoughts

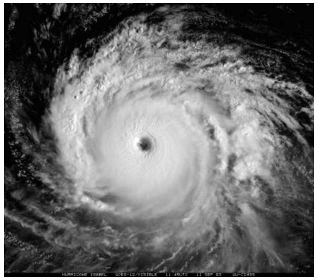
- The impact of the dynamical core on tropical cyclone statistics for the decadal experiments is significant. Needs to be explored more!
- The high-resolution CAM5-SE produces ***less*** tropical storms and hurricane per year than observed from 1980-2005 and ***more*** than that seen in the previous CAM5-FV AMIP simulation.
- As the climate warms the number of tropical cyclones decreases in CAM5-SE. However, the most intense storms become more intense.
- Need to focus on understanding some of the regional and intensity biases that exist in CAM5-SE.

TCCIP
2015IWCC



Reduced Complexity Testbeds

ICCIP
2015IWCC



How do we evaluate GCMs?

- Utilize a test hierarchy

Increasing Complexity

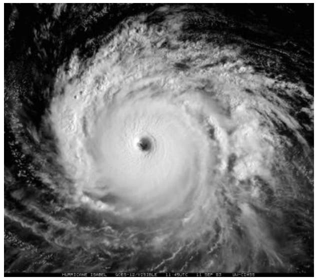
2D Shallow Water Test Cases → 3D Dry Dynamical Core Test Cases → MISSING LINK: 3D Dynamical + Moist Simple-Physics Test Cases → 3D Aqua-Planet Experiment → 3D AMIP

Deterministic tests

Tests of the **statistical** behavior (model 'climate')

TCCIP 2015 TWNCC

 [Reed & Jablonowski 2012, JAMES]

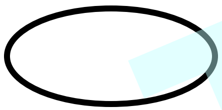


Simple-Physics

Dynamical Core

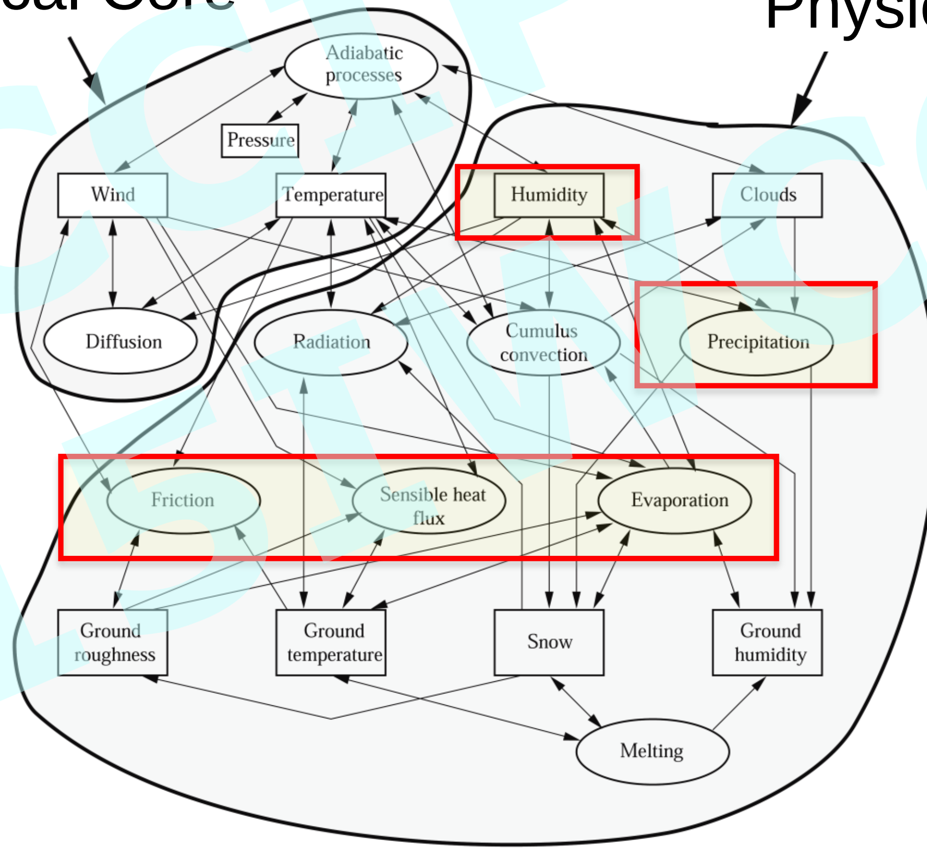
Physics

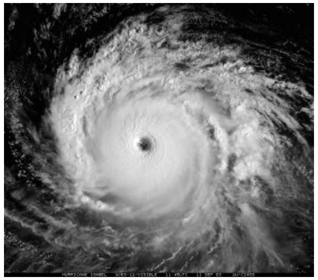
Process



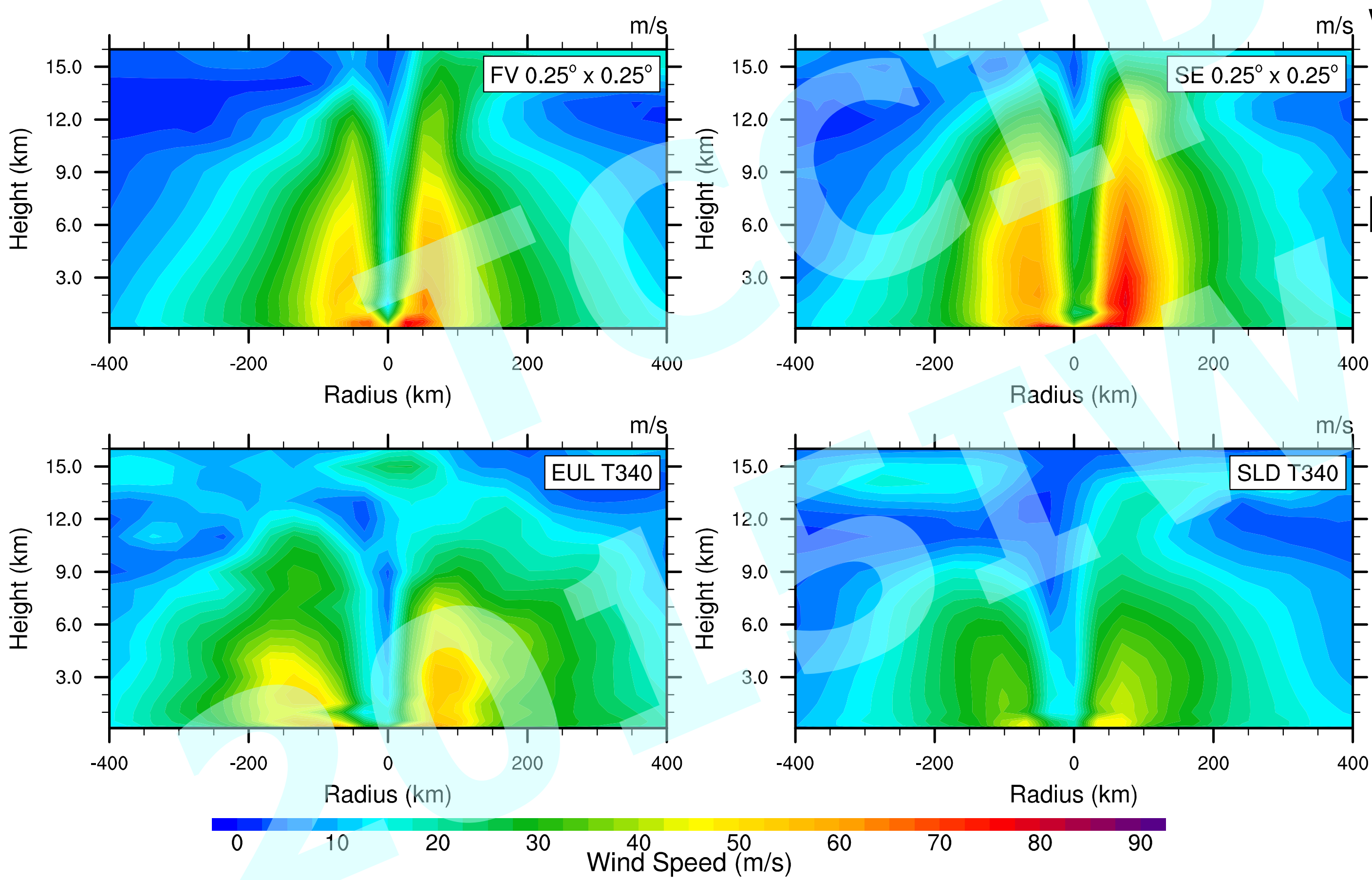
Variable

Interaction





Simple-Physics Dynamical Core Comparison



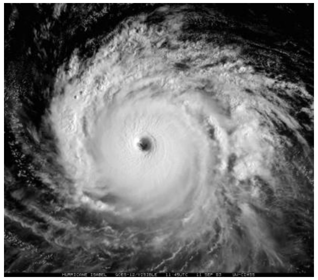
Wind Speed (m/s)
At Day 10

Differing strengths and shapes:

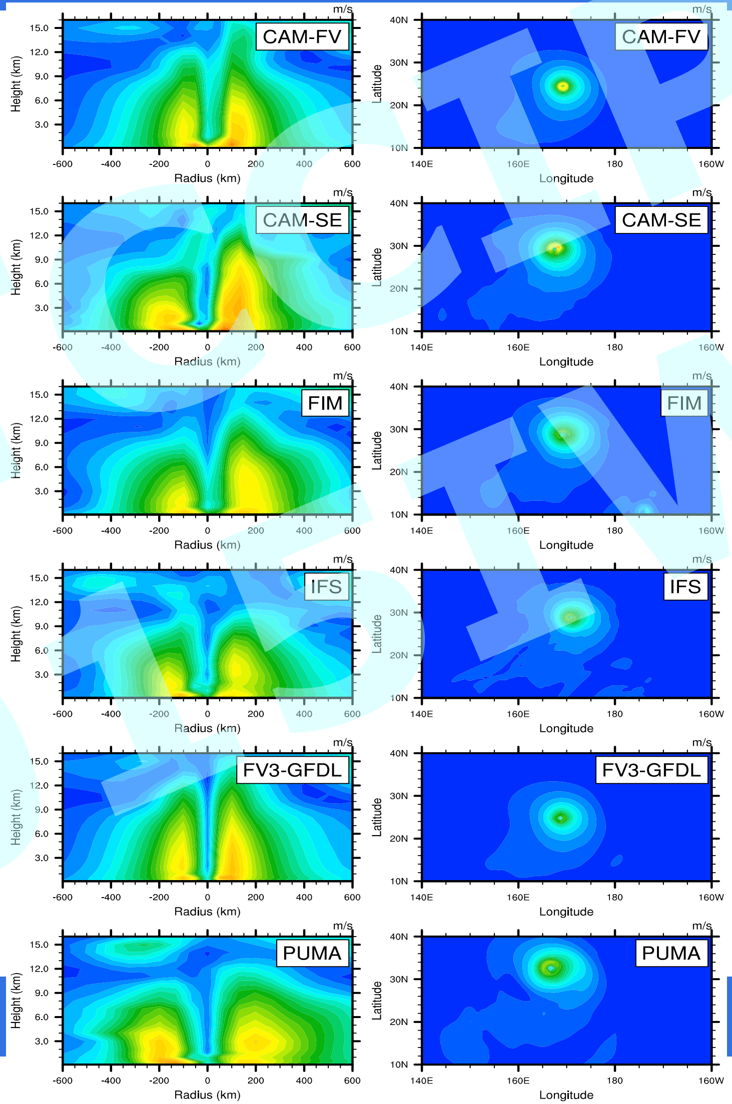
FV & SE
at 0.25°
(≈ 28 km)

EUL & SLD
at T340
(≈ 39 km)

[Reed & Jablonowski 2012, JAMES]



The Dynamical Core Model Intercomparison Project (DCMIP)

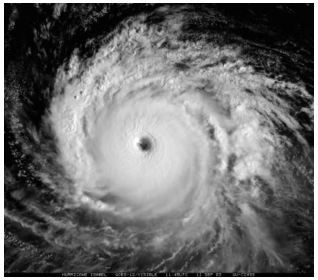


Simple-physics

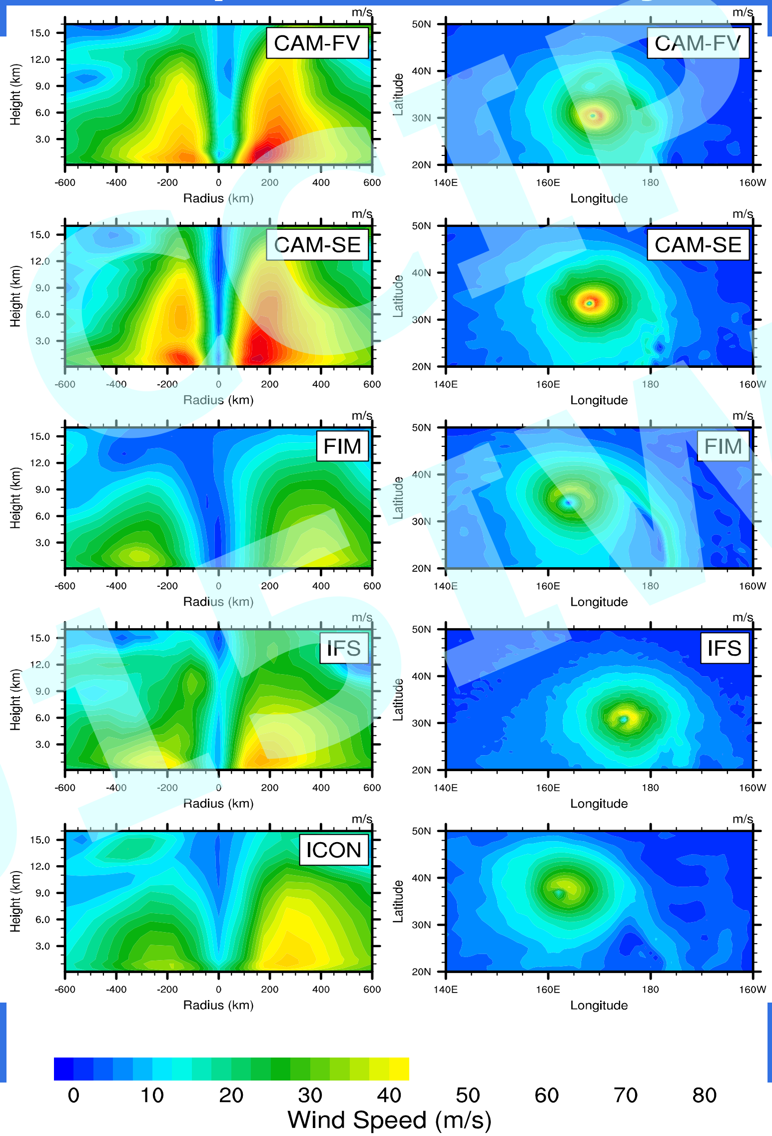
Wind Speed (m/s)
At Day 10

For equivalent **0.5°** resolution w/
30 levels

2015 TCCIP WCC



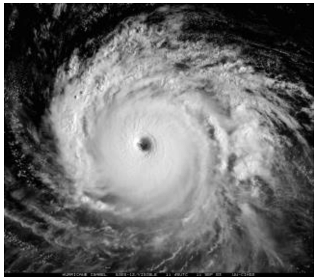
The Dynamical Core Model Intercomparison Project (DCMIP)



Full model physics

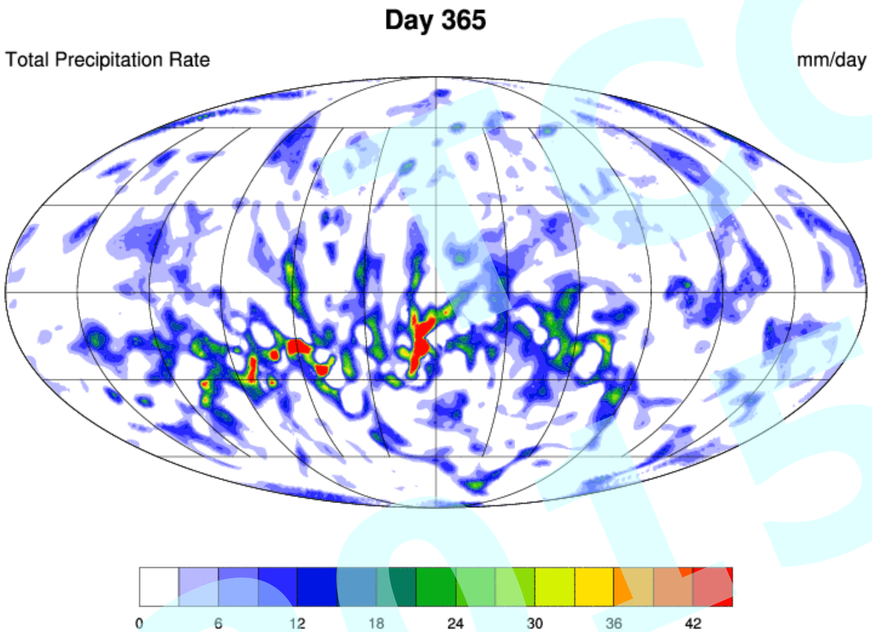
Wind Speed (m/s) At Day 10

For equivalent **0.5^o** resolution w/ **30 levels**

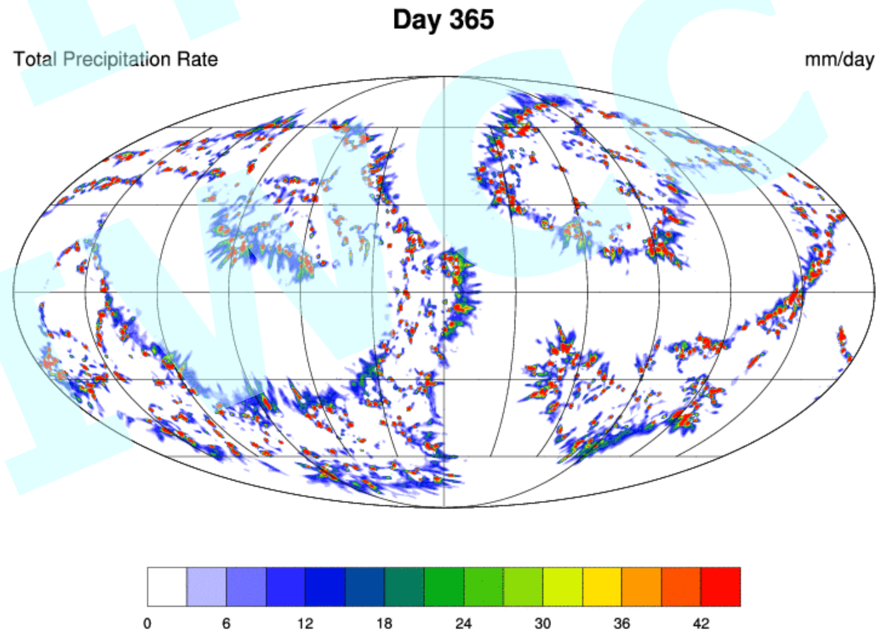


Non-rotating RCE World: Resolution Sensitivity

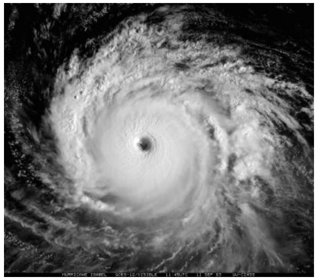
6-hr Avg. Precipitation (mm/day)



ne30 (~100 km)



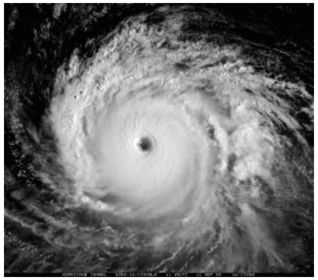
ne120 (~25 km)



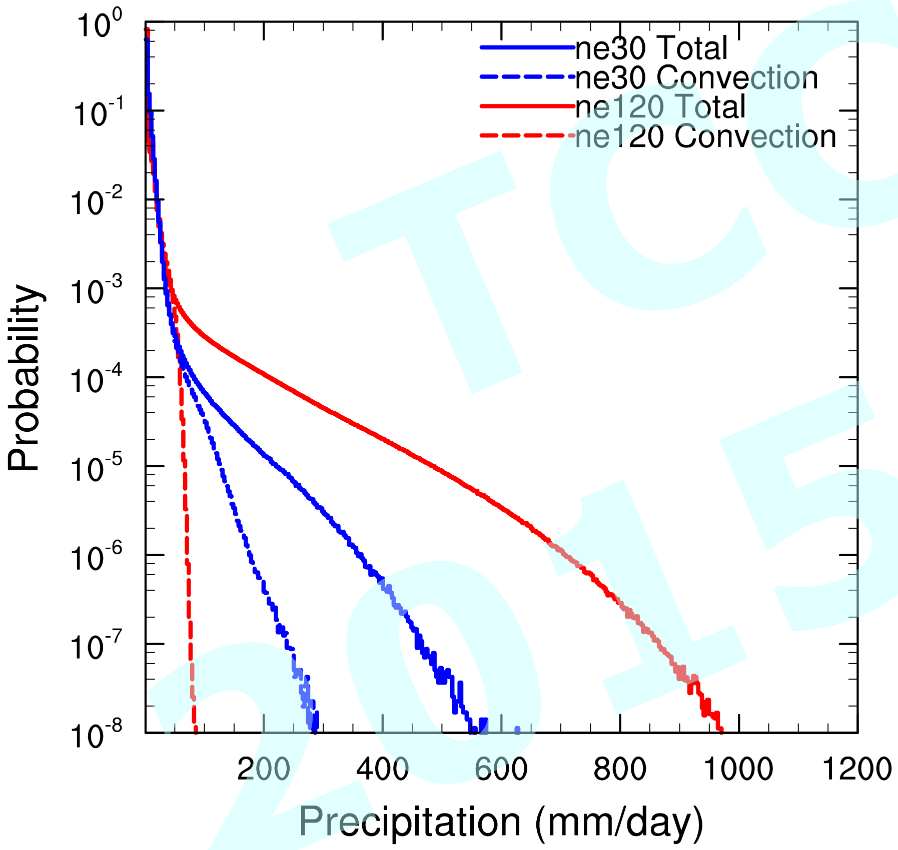
Design of Experiments

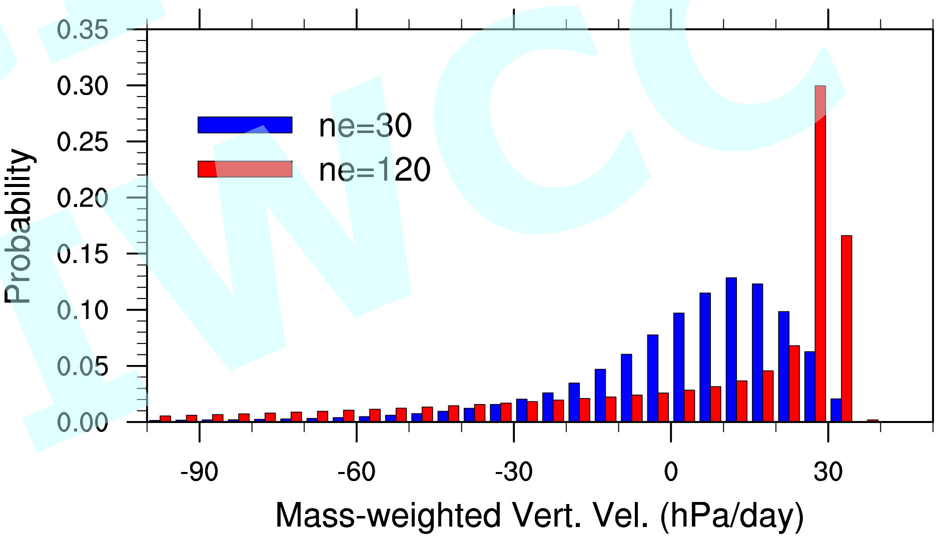
- NCAR's Community Atmosphere Model version 5.3 (CAM 5.3).
- The SE dynamical core with 30 vertical levels is used at the horizontal resolutions of:
  - ne=30 (~100 km)
  - ne=120 (~25 km)
- Full physics in Aquaplanet mode is used, with a simplified ocean covered Earth and constant SST of 29^{o} C.
- No rotation effects or spatially uniform rotation effects.
- Diurnally varying, spatially uniform insolation (~340 W/m^{2}).
- No direct and indirect effects of aerosols.
  - Tuning parameters are set to ne=30 configuration for all simulations.

2015 TCCIP WCC



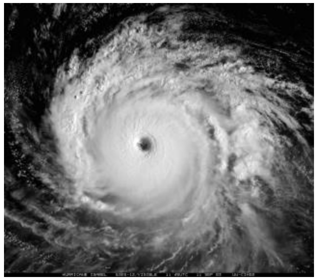
Non-rotating RCE World: Precip Extremes





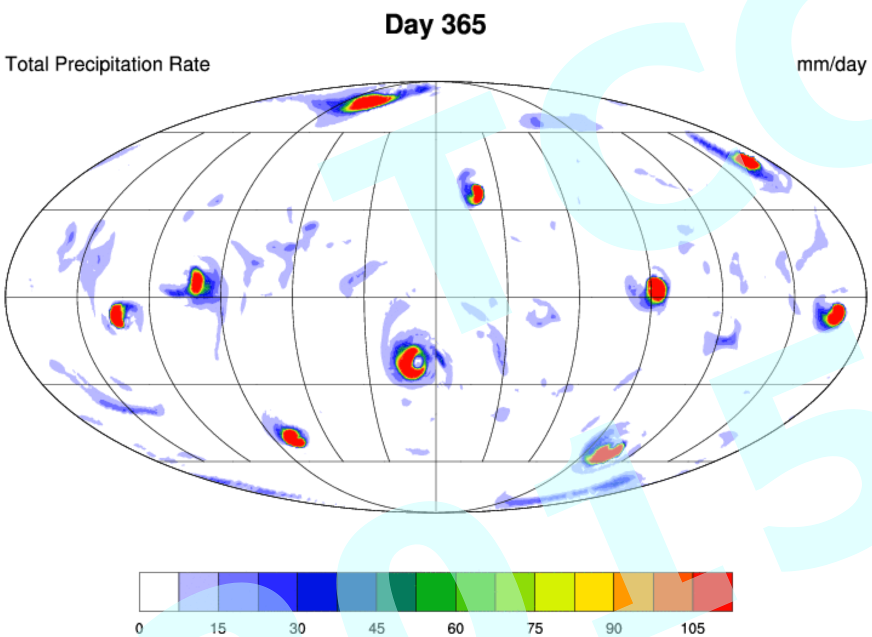
TCCIP 2015IWCC

[3 mm/day bins]

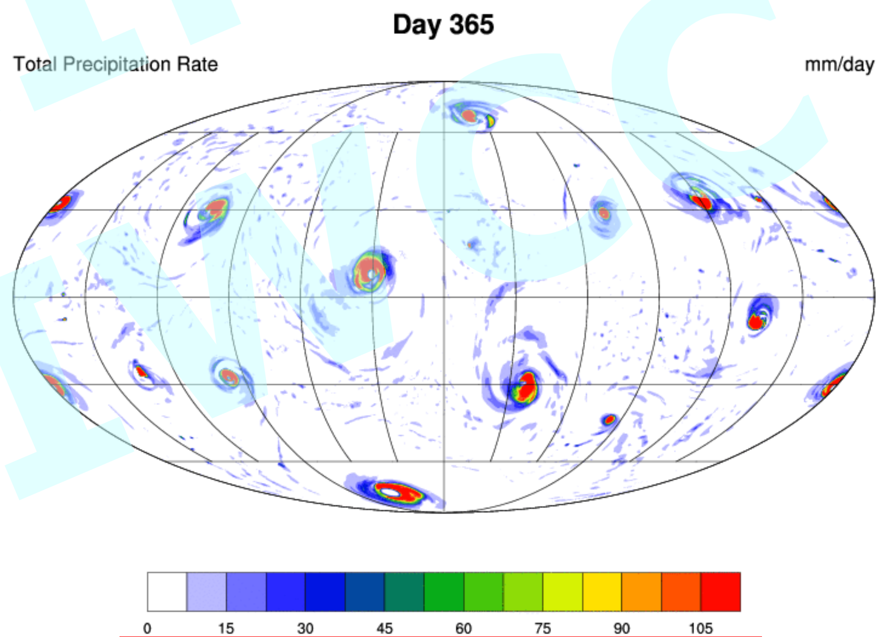


Uniformly rotating RCE World

6-hr Avg. Precipitation (mm/day)

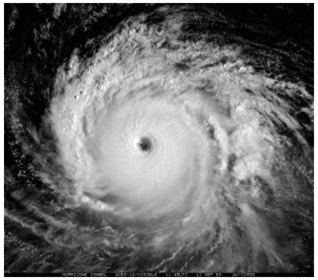


CAM5-SE ne30 (~100 km)



CAM5-SE ne120 (~25 km)

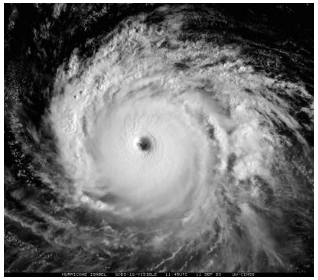
[Corilois set to 10 deg. N]



Summary

- The impact of the dynamical core on tropical cyclone statistics for the decadal experiments is significant.
- Not all biases are improved with resolution.
- Plan to run ensemble simulations (approx. 4) for the AMIP and RCP scenarios, as well as use different techniques for the prescribed SSTs in the RCP scenarios.
- Reduced complexity testbeds can provide an opportunity to evalutate next-generation models earlier on in development.

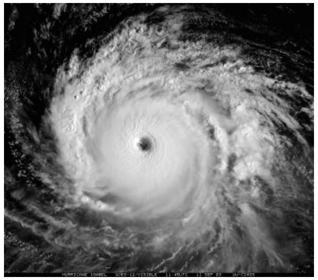
TCCIP 2015IWCC



Thanks!

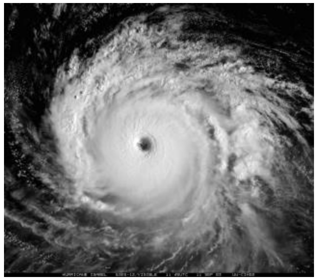
contact: kevin.a.reed@stonybrook.edu

TCCIP 2015IWCC

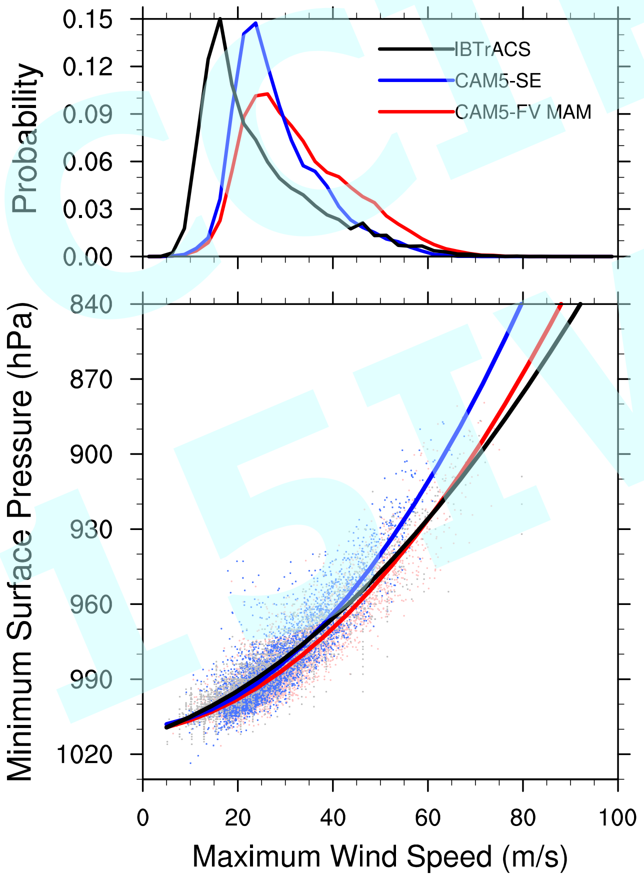


Extra:
Aerosol Model Impact

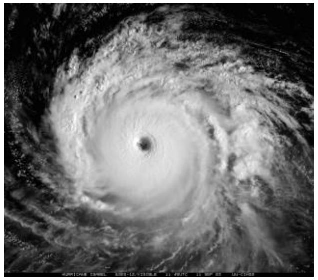
TCCIP 2015IWCC



Extra:
Aerosol Model Impact



TCCIP 2015 TWCC



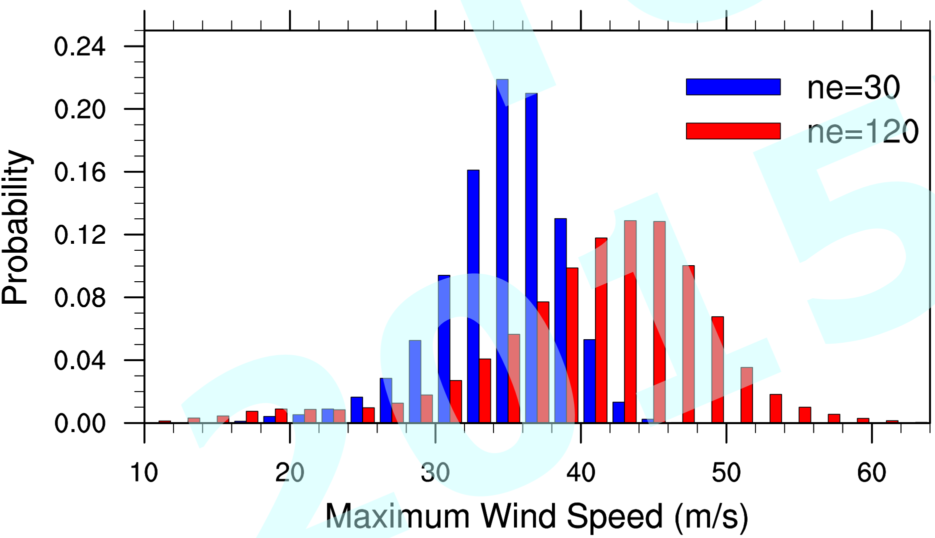
Uniformly rotating RCE World

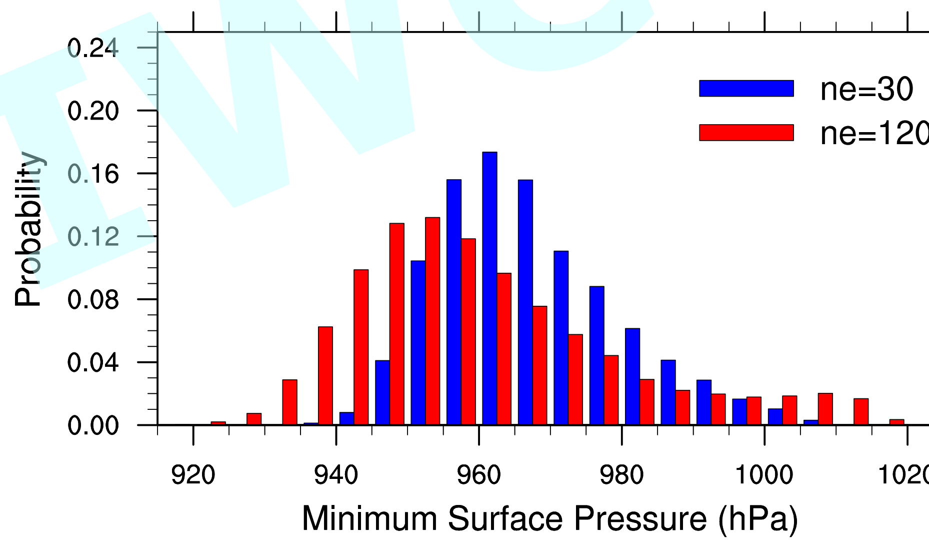
ne30:

- Avg. Count = 10.9
- Avg. Max. Wind = 34.7 m/s
- Avg. Min. PS = 967 hPa

ne120:

- Avg. Count = 13.6
- Avg. Max. Wind = 40.9 m/s
- Avg. Min. PS = 961. hPa





TCCIP 2015WCC