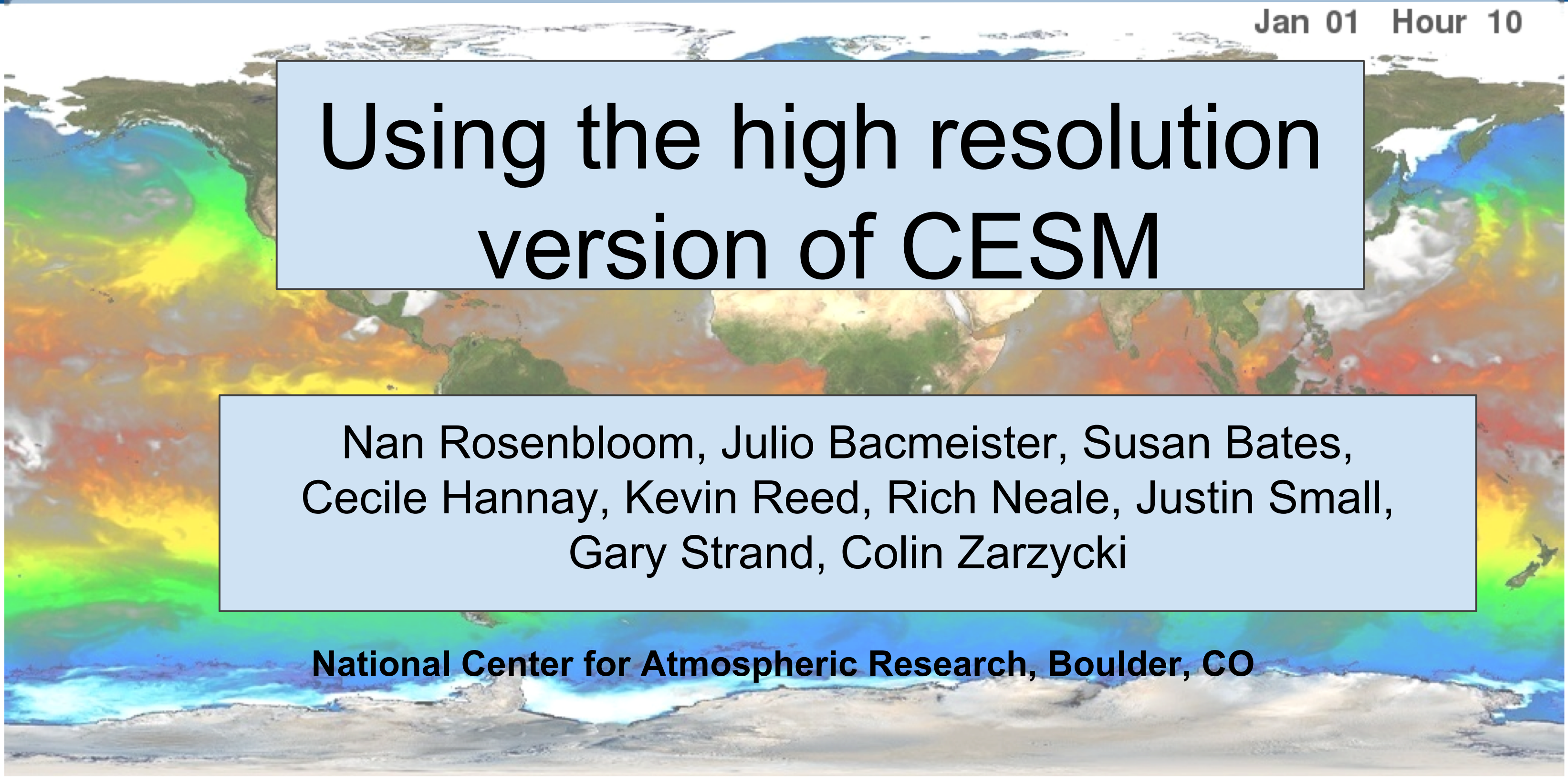


# Using the high resolution version of CESM

Nan Rosenbloom, Julio Bacmeister, Susan Bates, Cecile Hannay, Kevin Reed, Rich Neale, Justin Small, Gary Strand, Colin Zarzycki

**National Center for Atmospheric Research, Boulder, CO**

CESM Tutorial, NCAR, Boulder, CO August 6-10, 2018

# Outline

- ❑ Motivation for using high resolution CESM
- ❑ What do we mean by “high resolution”
- ❑ Dynamical core:  FV vs SE
- ❑ Benefits* vs costs
- ❑ Applications
- ❑ High resolution → High frequency output

*CESM2 High resolution has not been released → CESM2.1

# Outline

- ❑ Motivation for using high resolution CESM
- ❑ What do we mean by “high resolution”
- ❑ Dynamical core:  FV vs SE
- ❑ Scientific benefits* vs technical costs
- ❑ Applications
- ❑ High resolution → High frequency output

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# CESM2 Tutorial

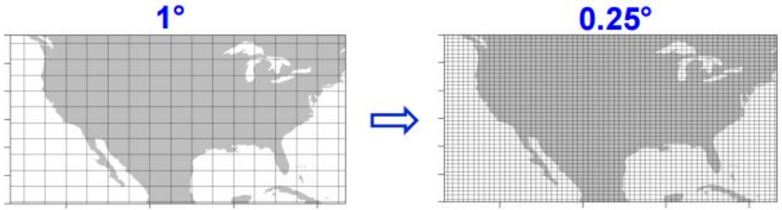
| | Tutorial | High Resoln |
|---|---|---|
| Atmosphere version | CAM6 | CAM-SE |
| Atmosphere Resolution | ~100km | ~28km |
| Ocean Resolution | 1$^{o}$ | 1$^{o}$ / 0.1$^{o}$ |
| Throughput (24 wallclock) | 20+ yrs/day | ~1-2 yrs/day |

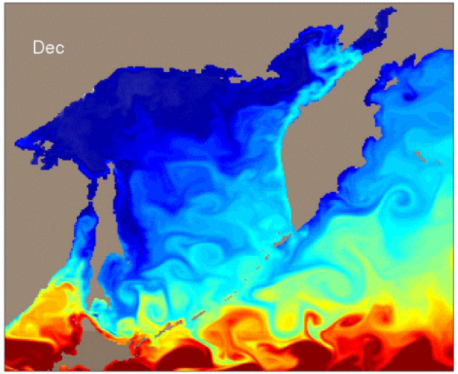
All the examples in this presentation use
CESM1/CAM5/CLM4.0/CICE

# Motivation

Increasing model resolution may allow us to:

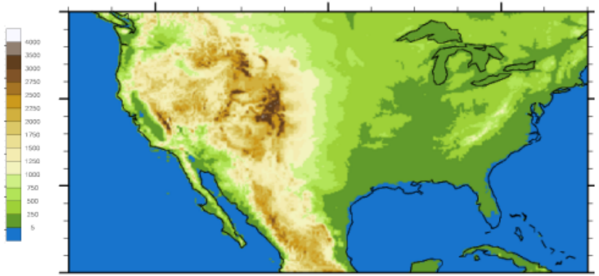
- ❑ **Reduce** the need to **parameterize processes**
- ❑ **Better resolve processes**: convection, precipitation, ocean eddies and boundary currents, improve the eastern boundary SST bias, mescoscale convective systems (MCSs)
- ❑ Detect **highly localized storms:** tropical cyclones, hurricanes, mid-latitude storms, tornadoes



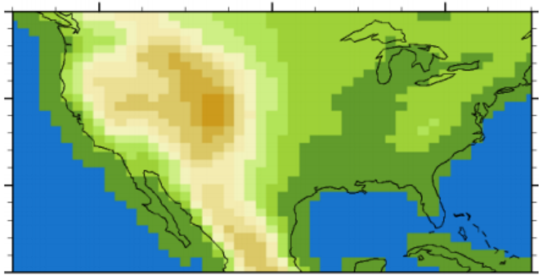



# What do we mean by high resolution

**Observation**

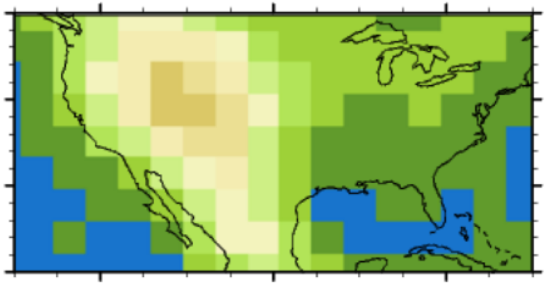


**CAM at 1 degree (standard resolution)**

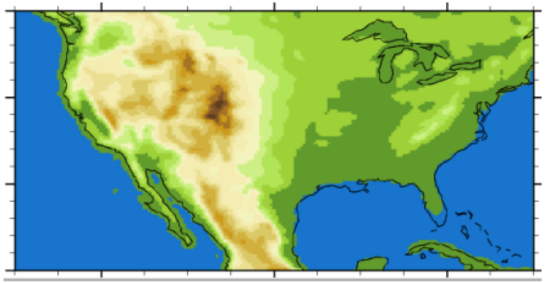


**Tutorial** ←

**CAM at T31**



**CAM at 0.25 degree (high resolution)**



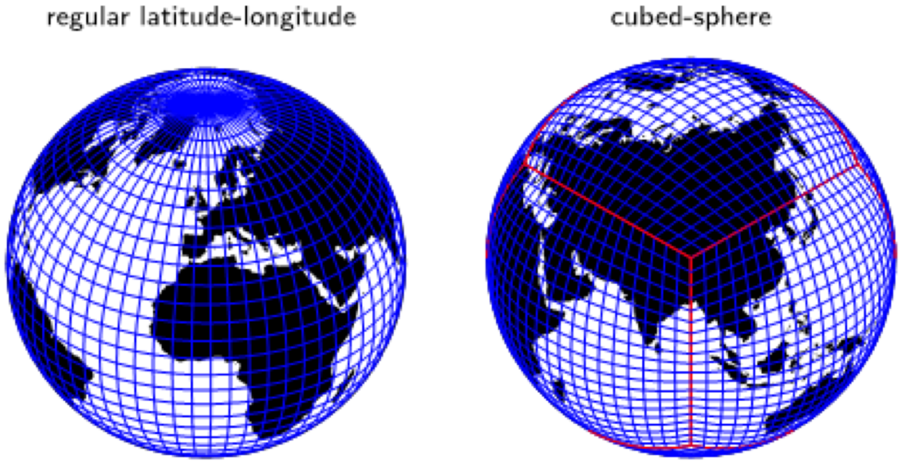
**High Resoln** ←



*Slide courtesy of Cecile Hannay*

# Dycore: Finite Volume (FV) vs CAM-SE

**Benefits**:
- ❑ Unstructured grid: ~uniform cells
- ❑ No convergent pole → less filtering → faster (primary reason we use SE instead of FV0.25)
- ❑ Able to do regional refinement




**Cons**:
- ❑ Different biases
- ❑ Vector output format from CAM-SE is hard to visualize

**High resolution atmosphere**



*Slide courtesy of Peter Lauritzen*

# Resolution + dynamical core

| Atmosphere grid | Resoln | Atm/Land | Ocean/Ice |
|---|---|---|---|
| Spectral low resolution | T31_gx3v7 | 3.75° | 3° |
| Finite volume low resolution | f45_gx3v7 | 4° | 3° |
| **Finite volume low resolution** | **f19_gx1v6** | **2°** | **1°** |
| **Finite volume moderate resolution** | **f09_gx1v6** | **1°** | **1°** |
| Finite volume high resolution (hdeg) | f05_gx1v6 | 0.5° | 1° |
| Finite volume high resolution | f02_gx1v6 | 0.25° | 1° |
| Spectral element moderate resolution | ne30_gx1v6 | 1° | 1° |
| **Spectral element high resolution** | **ne120_gx1v6** | **0.25°** | **1°** |
| **Spectral element high resolution** | **ne120_t12** | **0.25°** | **0.1°** |

*Tutorial* → Finite volume low resolution (f19_gx1v6)

*LENS* → Finite volume moderate resolution (f09_gx1v6)

*High Res Atm* → Spectral element high resolution (ne120_gx1v6)

*High Res Atm+Ocn* → Spectral element high resolution (ne120_t12)

**Finite Volume**

**CAM-SE**

# Some things improve .. (CAM5)

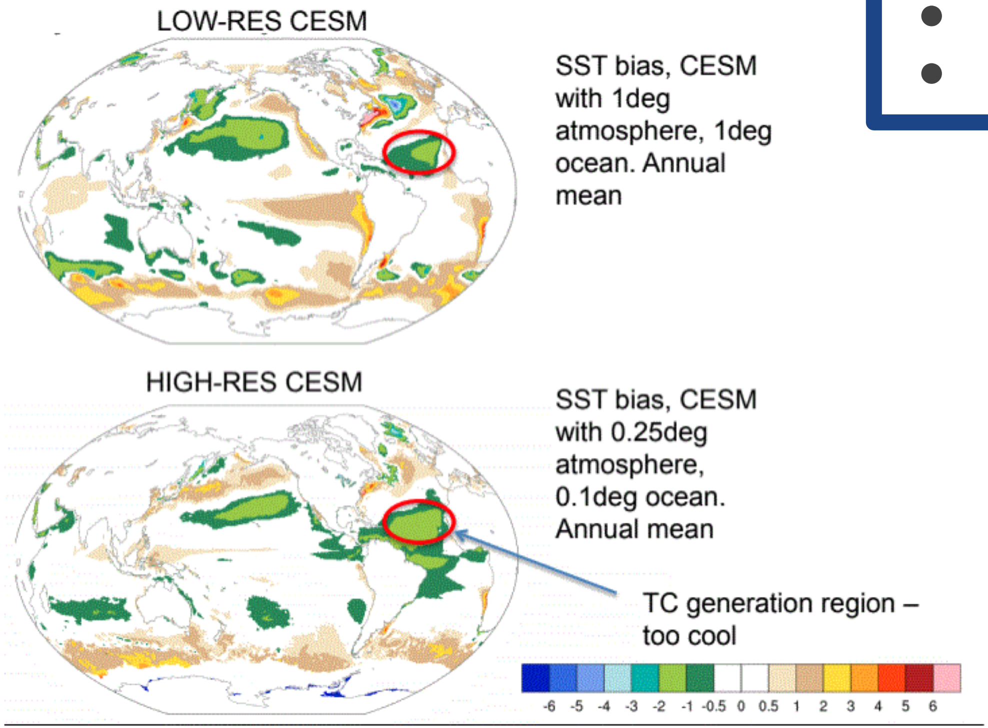
**Atmosphere**:
- Tropical cyclones
- Extreme precipitation
- Eastern boundary SST
  - Improved coastal jets in the atmosphere

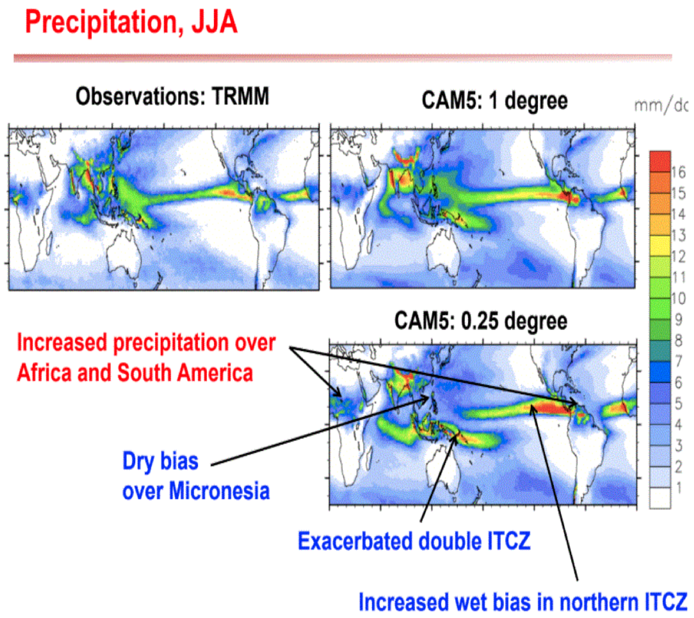
**Ocean**:
- Eddies
- Western boundary currents and SST
- Small scale air-sea interactions; atmosphere boundary layer responding to SST
- ENSO … ? Looks good in ASD run but data and observations are short

*Courtesy of Cecile Hannay*

# Some biases may persist (CAM5)

- Deep ocean warming
- Double ITCZ remains + strengthens
- Persistent cool Atlantic




*Courtesy of Cecile Hannay*

# Weighing Costs vs Benefits

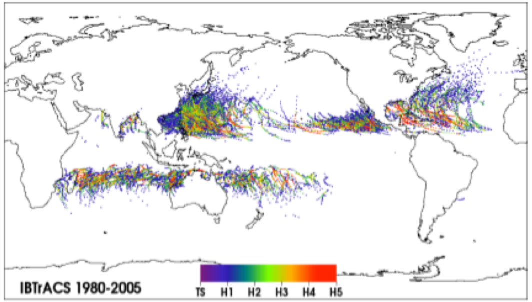
**Pros**:

- Better **resolve processes**: convection, precipitation, ocean eddies and boundary currents, eastern boundary SST improved
- Can detect **highly localized storms** like tropical cyclones and mid-latitude storms

**Cons**:

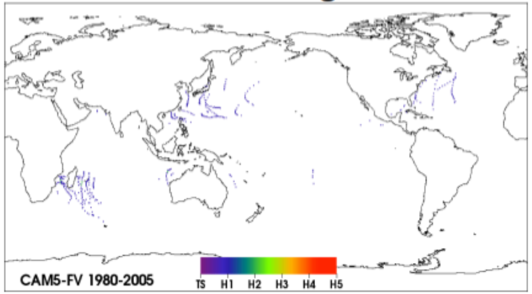
- Costs: **Storage** + **production**
- High resoln **spatial** + **temporal** output
- TC detection requires **HF output**
- Cyclone tracking → 3-6 hrly (WMO standard is 6 hrly)
- Bias reduction can be mixed
- Post-processing+data management
- **Ensembles vs high resolution**

**Observations: IBTrACS**

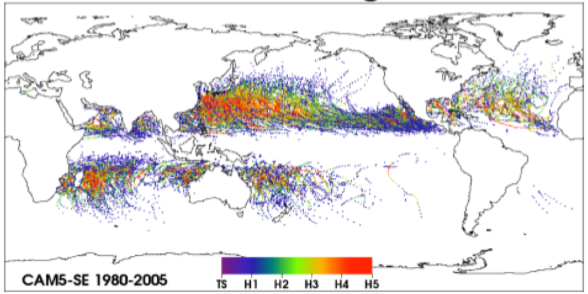



- **Tropical cyclone tracks identified by GFDL tracking algorithm**
- **CAM5 at 0.25 degree has some skills to simulate tropical cyclones**

**CAM5: 1 degree**




**CAM5: 0.25 degree**




*Courtesy: Kevin Reed* [See also: Wehner et al. 2014, JAMES]

# Costs: Data volume - Atm

| Frequency | Field | Number of Variables | Gigabytes per year |
|---|---|---|---|
| Daily | Single level | 10 | 11 |
| 6 hourly | Single | 24 | 68 |
| 6 hourly full field | Full field | 9 | 1300 |
| 3 hourly | Single level | 25 | 230 |
| 3 hourly full field | Full field | 5 | 1400 |
| 1 hourly | Single level | 1 | 27 |
| | **Total** | **74** | **2900 Gbytes/yr** |

# Ratio of output volume relative to default model configuration

Ratio of data volume to standard resolution

| Resolution | Standard output | High frequency output |
|---|---|---|
| 1 deg atm + 1 deg ocn | 1 | 2.7 |
| 0.25 deg atm + 1 deg ocn | 8 | 36 |
| 0.25 deg atm + 0.1 deg ocn | 11 | 73 |

| Resolution | Total (Tb) | Total model yrs | Tb/model year |
|---|---|---|---|
| 1 deg atm + 1 deg ocn | 510 | 14000 | 0.04 |
| 0.25 deg atm + 1 deg ocn | 50 | 156 | 0.32 |
| 0.25 deg atm + 0.1 deg ocn | 140 | 55 | 2.55 |

# Costs: Data volume - Ocean

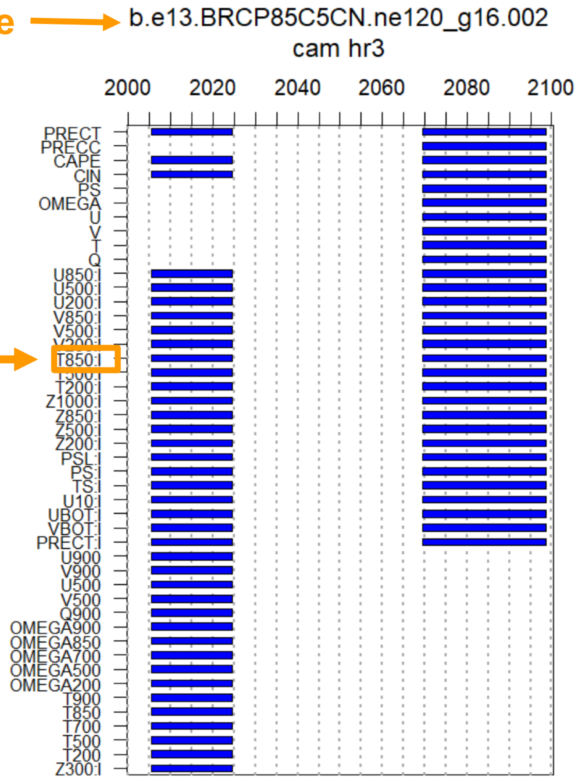
## Example with daily output

| | | # vars | 1 degree | 10th degree |
|---|---|---|---|---|
| | | | 30 levels | 62 levels |
| | | | 320x384 | 2400x3600 |
| Daily | Single level | 29 | 5 | 340 |
| Daily | Full field | 4 | 33 | 4700 |
| | **Total** | **33** | **38 Gbytes/yr** | **5040 Gbytes/yr** |

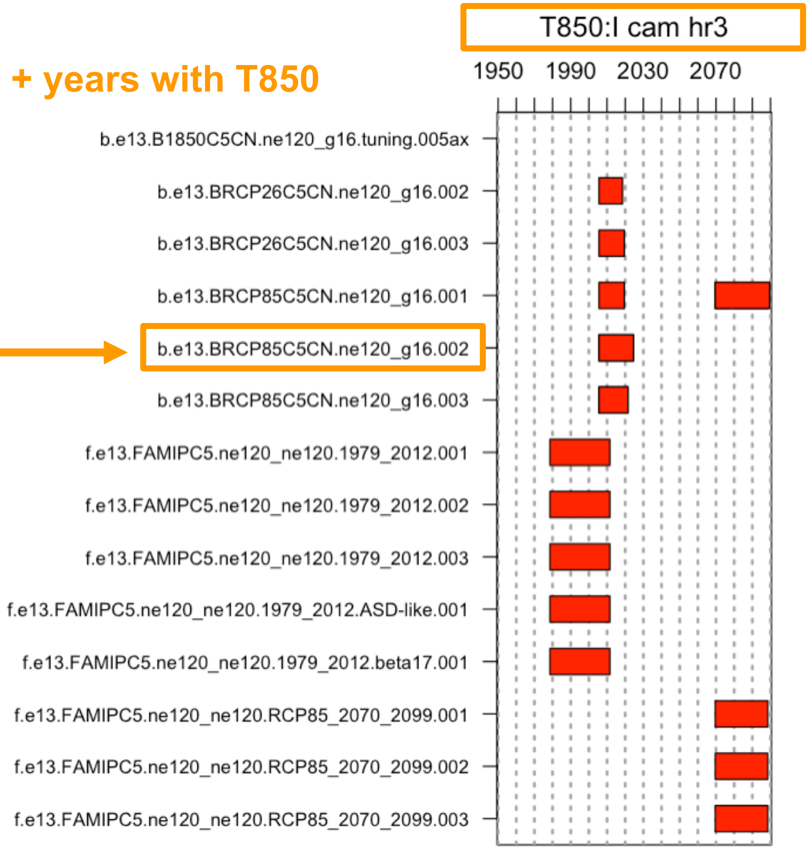
# Data management

Case

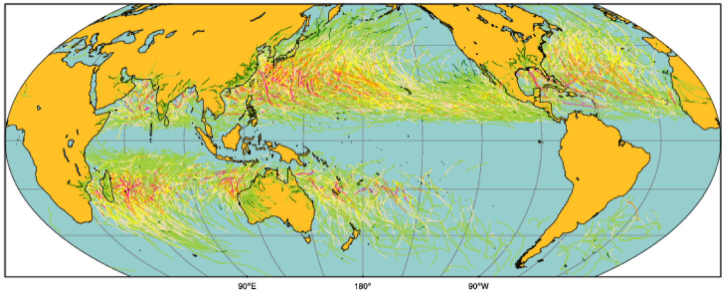
Variable

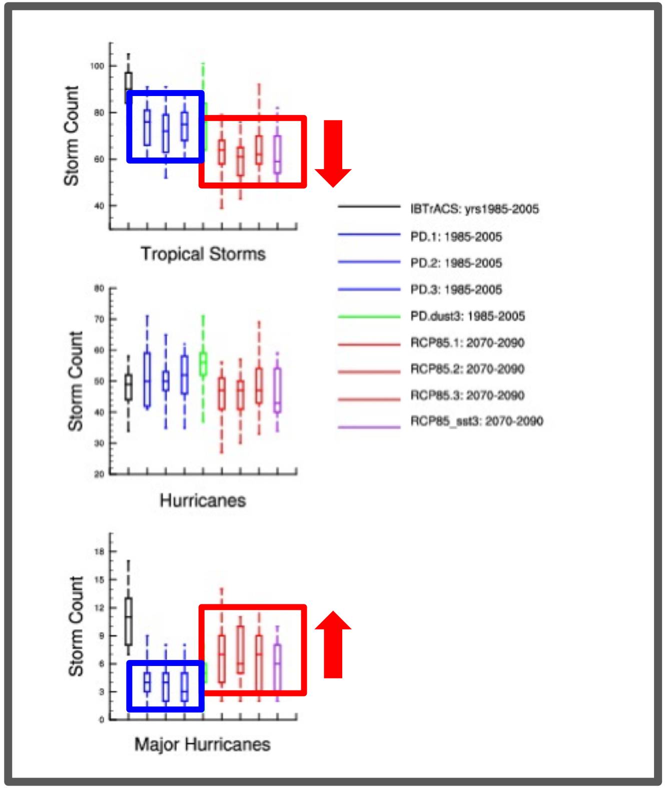



Case + years with T850



# Applications: Tropical Cyclones



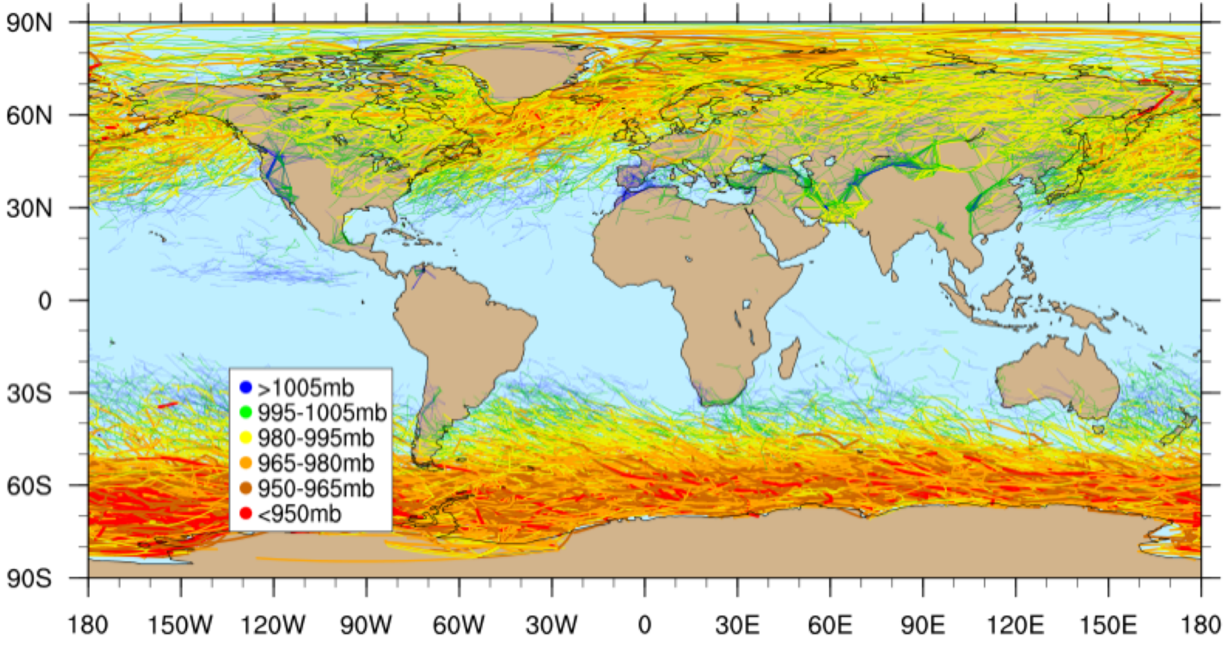

**Motivation**:

- ❑ Understanding how TC may change in a warming world is important to science and society.
- ❑ Model results indicate that 0.25° CAM5-SE has skill in simulating TCs.

**Methods + Results:**

- ❑ GFDL cyclone tracker
- ❑ **Reduction** in overall TC activity
- ❑ **Increase** in frequency of very intense TCs

# Applications: Extratropical storms

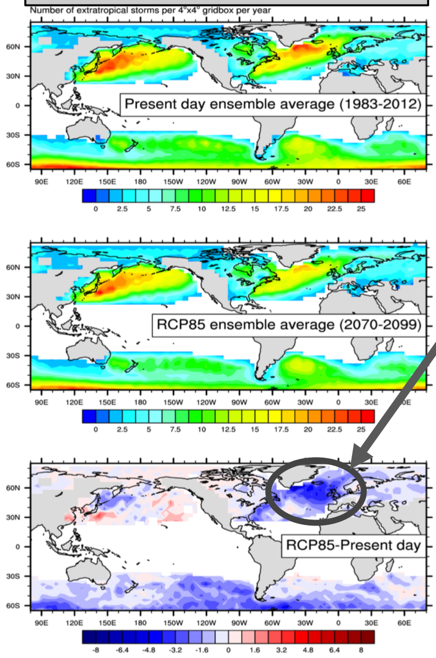



We also look at changes in mid-latitude storms using TempestExtremes

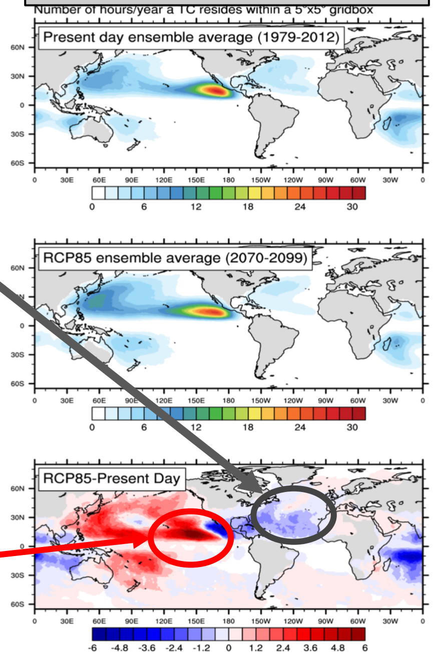
*(Ullrich and Zarzycki, 2016)*

# Applications: TCs + ETCs

## Mid-latitude



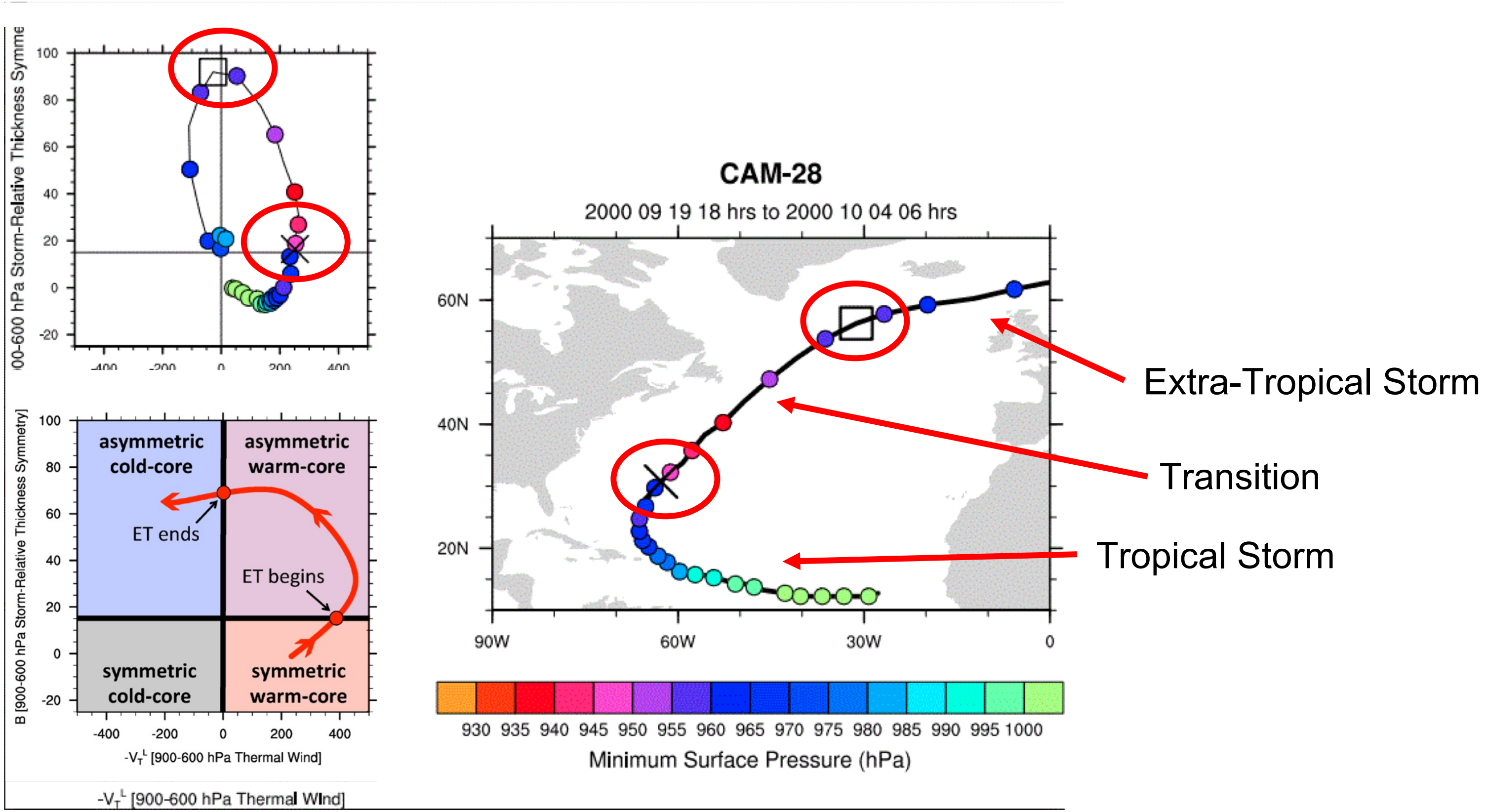

## Tropical




Future scenarios indicate **weaker** mid-latitude and tropical storms in the North Atlantic

Future scenarios show **more** and **stronger** storms in the Eastern Pacific

# Detecting the extratropical transition of tropical cyclones

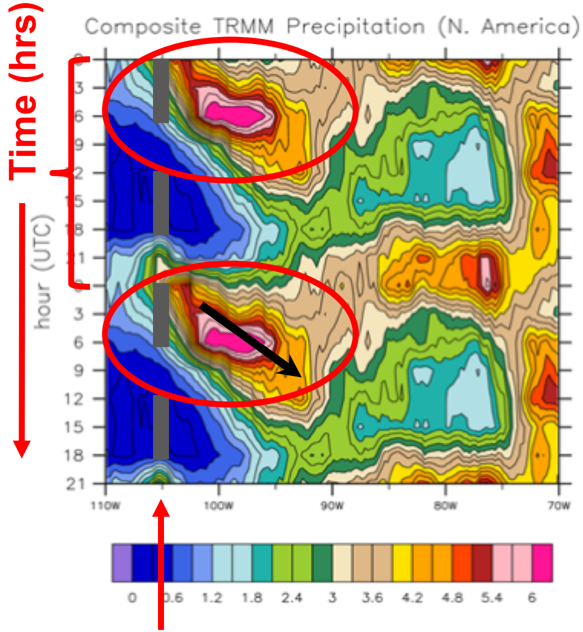



*Courtesy of Colin Zarzycki*
*(Zarzycki et al. (2017) JAMES)*

# Eastward Propagation of orographic precip

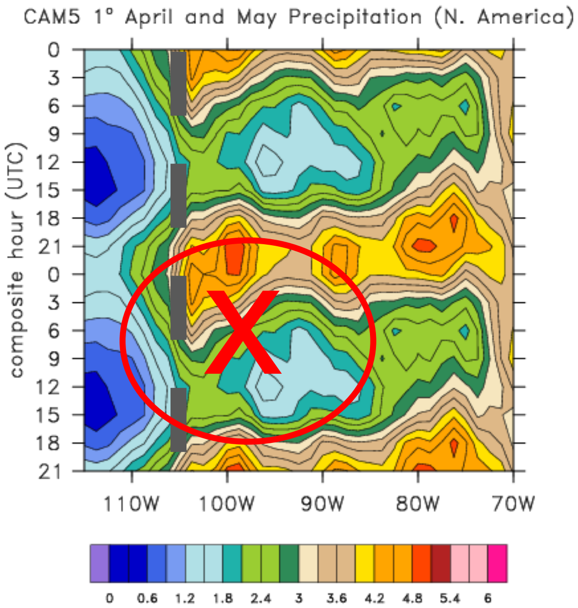
**Storms form in the lee of the Rockies and move East across the Great Plains**

**Observed**



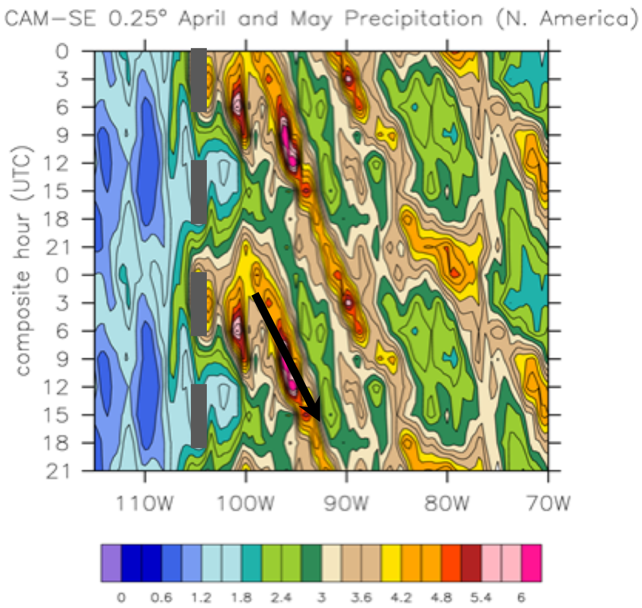

**Rocky Mountains**

**CAM5 1 degree**

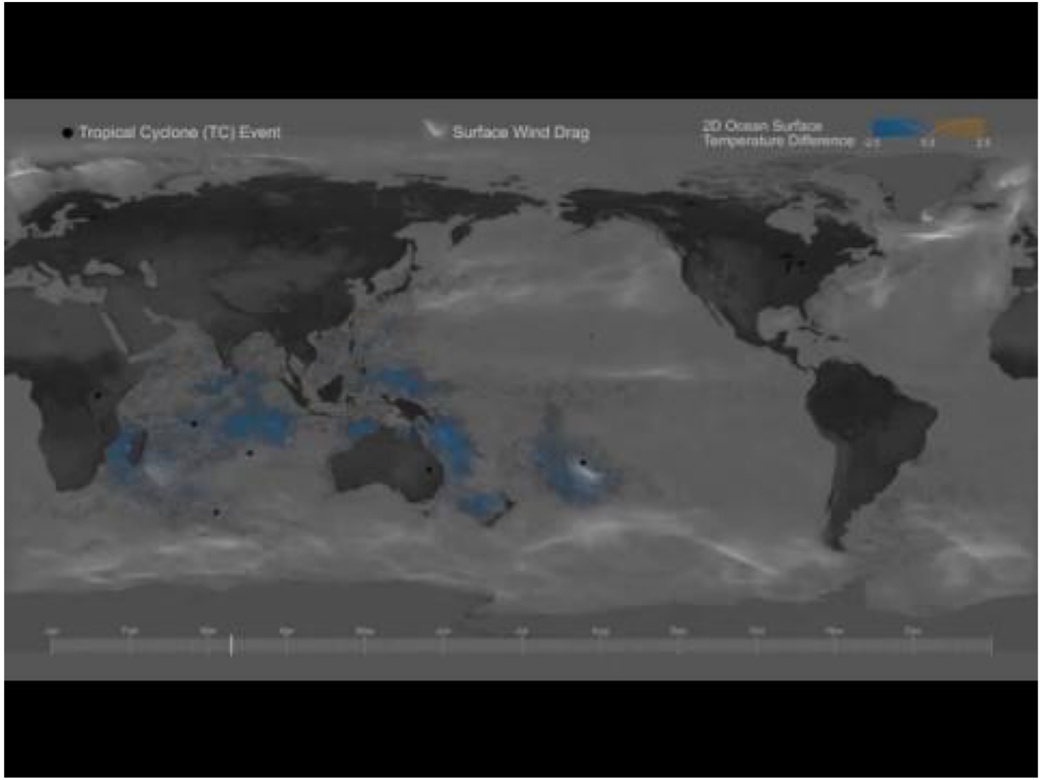



mm/day

**CAM5 0.25 degree**



# Animation




*Animation courtesy of Ryan Sriver, UIU-C, NCSA*

# Summary

- High resolution → 0.25$^o$ atm/land + 1$^o$ (or 0.1$^o$) ocean/ice
- Dynamical core → **CAM-SE**
- **Better resolve processes** that we've previously had to parameterize.
- Better resolve **topographic** features: dynamics and precipitation
- Improvement to boundary currents in ocean, and coastal jets in the atmosphere
- May improve some biases, and create new ones
- High production + storage costs
- High **spatial** resolution + high freq **temporal** output = **BIG DATA**
- **High resolution** vs **ensembles**

# Questions?