A grayscale image of a marble bust of the Greek goddess Athena. She is wearing a tall, pointed helmet (the Athena Parthenos helmet) and a draped garment with intricate carvings on the chest. Her expression is serene and contemplative.

Revolutionizing Climate Modeling through Dedicated High-End Computing: Project Athena

APEC Climate Symposium

23 June 2010

APCC– Busan, South Korea

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 people in 6 groups on 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)

Origin of Project

- The World Modeling Summit (WMS) in May 2008 at ECMWF called for revolution in climate modeling to more rapidly advance improvement in climate model resolution, accuracy and reliability
- The WMS recommended petascale supercomputers dedicated to climate modeling at at least 3 international facilities
 - Dedicated petascale machines are needed to provide enough computational capability and a controlled environment to support long runs and the management and analysis of very large (petabyte) data sets
- The U.S. National Science Foundation, recognizing the importance of the problem, realized that a resource (Athena supercomputer) was available to meet the challenge of the World Modeling Summit and offered to dedicate the Athena supercomputer over a six-month period in 2009-2010
- An international collaboration was formed among groups in the U.S., Japan and the U.K. to use Athena to take up the challenge

Science Goals

- *Hypothesis:* Increasing weather and climate model resolution to **accurately resolve mesoscale phenomena in the atmosphere** (and ocean and land surface) can dramatically improve the fidelity of the models in simulating the mean climate, the variances and covariances, and the representation of extreme events (already demonstrated that it improves the fidelity of cloud systems).
 - Better resolution = better representation of the laws of physics and of relevant boundary forcings (e.g. topography)
 - There are two dominant modes of instability in the atmosphere: baroclinic and convective. We should aspire to be able to simulate them both.
- *Hypothesis:* Simulating the **effect of increasing greenhouse gases on regional aspects of climate, especially extremes**, may, for some regions, depend critically on the spatial resolution of the climate model.

Collaborating Groups

COLA - Center for Ocean-Land-Atmosphere Studies, USA (NSF-funded)

ECMWF - European Center for Medium-range Weather Forecasts, UK

JAMSTEC - Japan Agency for Marine-Earth Science and Technology,
Research Institute for Global Change, Japan

University of Tokyo, Japan

NICS - National Institute for Computational Sciences, USA (NSF-funded)

Cray Inc.

Codes

NICAM: Nonhydrostatic Icosahedral Atmospheric Model

IFS: ECMWF Integrated Forecast System

Supercomputers

- **Athena:** Cray XT4 - 4512 quad-core Opteron nodes (18048)
 - #30 on Top500 list (November 2009) – dedicated Oct'09 – Mar'10
- **Kraken:** Cray XT5 - 8256 dual hex-core Opteron nodes (99072)
 - #3 on Top500 list (November 2009) replaced Athena – allocation of 5M SUs

Participants

ECMWF

- Mats Hamrud
- Thomas Jung
- Martin Miller
- Tim Palmer (co-PI)
- Peter Towers
- Nils Wedi

NICS

- Phil Andrews (co-PI)
- Troy Baer
- Matt Ezell
- Christian Halloy
- Dwayne John
- Bruce Loftis
- Kwai Wong

Cray

- Pete Johnsen
- Per Nyberg

JAMSTEC/U. Tokyo

- Chihiro Kodama
- Masaki Satoh (co-PI, U. Tokyo)
- Hirofumi Tomita (co-PI, JAMSTEC)
- Yohei Yamada

NSF

- AGS: Jay Fein
- OCI: Steve Meacham, Rob Pennington

COLA

- | | |
|------------------------|--------------------|
| - Deepthi Achutavarier | - Emilia Jin |
| - Jennifer Adams | - Jim Kinter (PI) |
| - Eric Altshuler | - Larry Marx |
| - Ben Cash | - Julia Manganello |
| - Paul Dirmeyer | - Cristiana Stan |
| - Bohua Huang | - Tom Wakefield |



National Institute for Computational Sciences



University of Tennessee and ORNL partnership

- NICS is funded by the National Science Foundation, is located at Oak Ridge National Lab, and is managed by the University of Tennessee
- NICS operates the first academic petascale supercomputer in the world
- Leverages the capabilities of the ORNL computing complex



NICS Lessons Learned

- Dedicated usage of a relatively big supercomputer greatly enhances productivity
- Dealing with small group of users and their requirements allows for more efficient utilization
- *Challenge*: Dedicated simulation projects like Project Athena can generate enormous amounts of data to be archived, analyzed and moved around.

Data management is a big challenge: should be studied carefully.

- Communication throughout the project is essential: (weekly telecons, email lists, personal calls, ...) - Project Athena demonstrated the value of developing good teamwork practices

Athena Experiments

	Resolution	Grid Size	# Cases	Time Period	Data Volume	Comments
NICAM		7 km	8*	103 days	639 TB	21 May - 31 Aug 2001-2009 * unable to complete 2003
IFS 13-month Hindcasts	T159	125 km	48	395 days	0.7 TB	1 Nov - 30 Nov (next year) 1960 - 2007
	T511	39 km			7 TB	
	T1279	15 km			41 TB	
	T2047	10 km	20		51 TB	
IFS 103-day Hindcasts	T159	125 km	9	102 days	0.03 TB	21 May - 30 Aug 2001 - 2009 (a la NICAM)
	T511	39 km			0.3 TB	
	T1279	15 km			2 TB	
	T2047	10 km			6 TB	
IFS 10-Member Ensembles (Summers)	T511	39 km	6	132 days	2.7 TB	Selected years
	T1279	15 km			17 TB	
IFS 10-Member Ensembles (Winters)	T511	39 km	6	151 days	3.2 TB	1 Nov - 31 Mar Selected years
	T1279	15 km			20 TB	
IFS AMIP	T159	125 km	1	47 years	0.6 TB	1961 - 2007
	T1279	15 km			38 TB	
IFS Time Slice	T159	125 km	1	47 years	0.6 TB	2071 - 2117
	T1279	15 km			38 TB	
Total					874 TB	

<http://iges.org/grads/athena>

Public Sharing of Athena Data via ESG

- NSF requires that data must eventually be publicly available
- Discussions have begun to serve a small subset of Athena data on a trial basis via *Earth System Grid (ESG)* - a network of nodes and gateways at national labs and research centers in the US that collectively support secure access to massive distributed data sets
- ESG can publish data that reside on tape under HPSS
- ESG also provides “Extending Services” (metadata search, subsets, server-side analysis, etc.)
- ESG Services are currently limited to data on spinning disk in CF-compliant NetCDF format
- If tests prove positive, a more substantial subset will be served via ESG

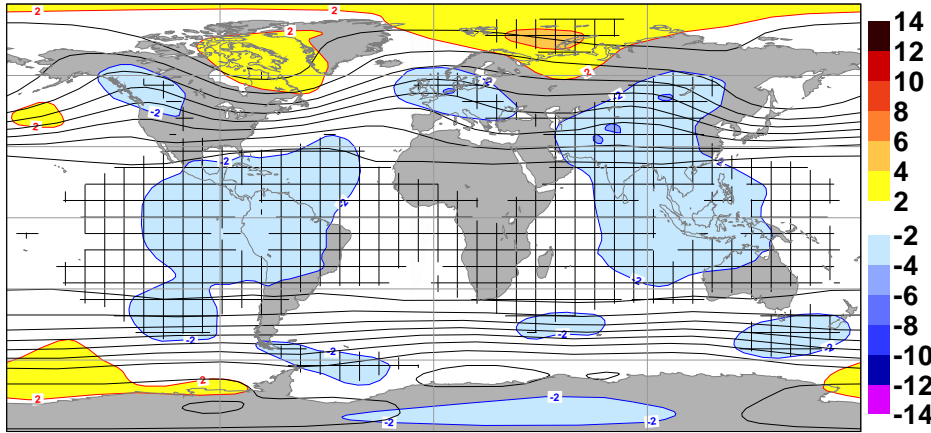


Selected Results

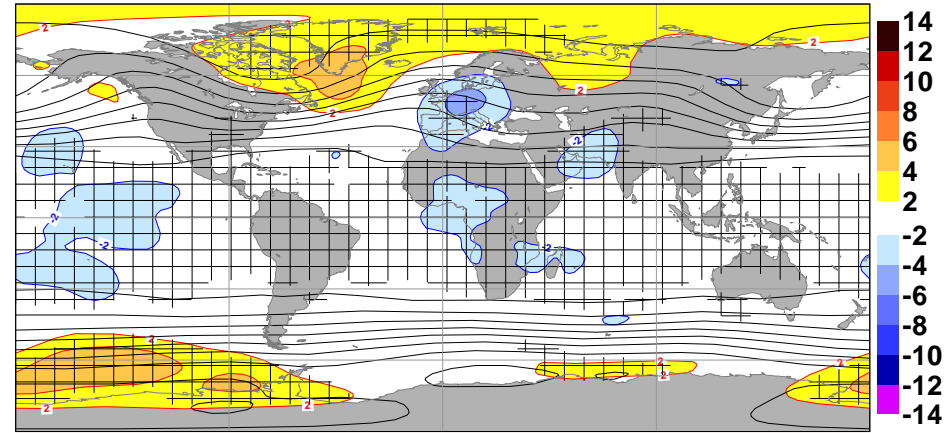
- Large-Scale Circulation
- Precipitation Climatology
- Asian Monsoon
- Resolution Dependence of Snow
- Simulation of Tropical Cyclones
- NICAM Simulation (21 May – 31 August 2009)

Mean Z500 Error (DJF 1989-2007)

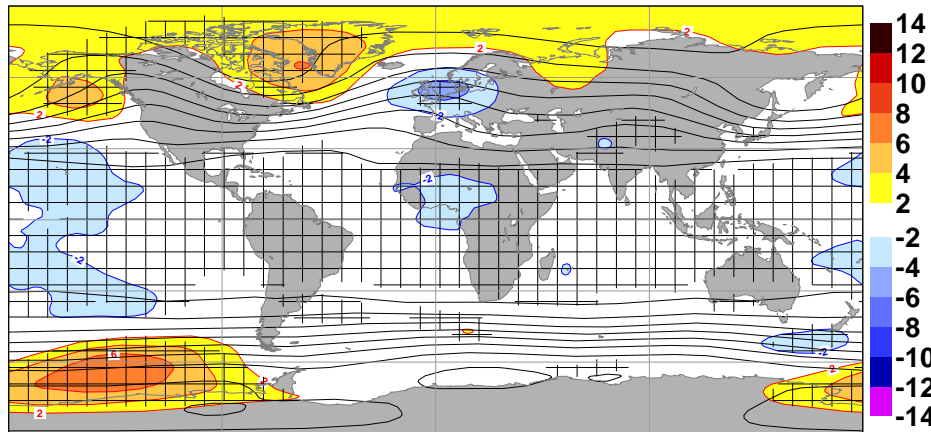
T159



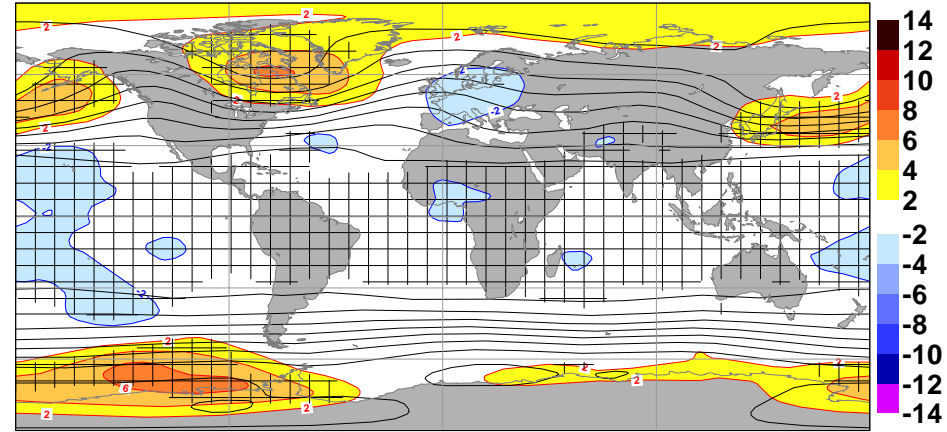
T511



T1279

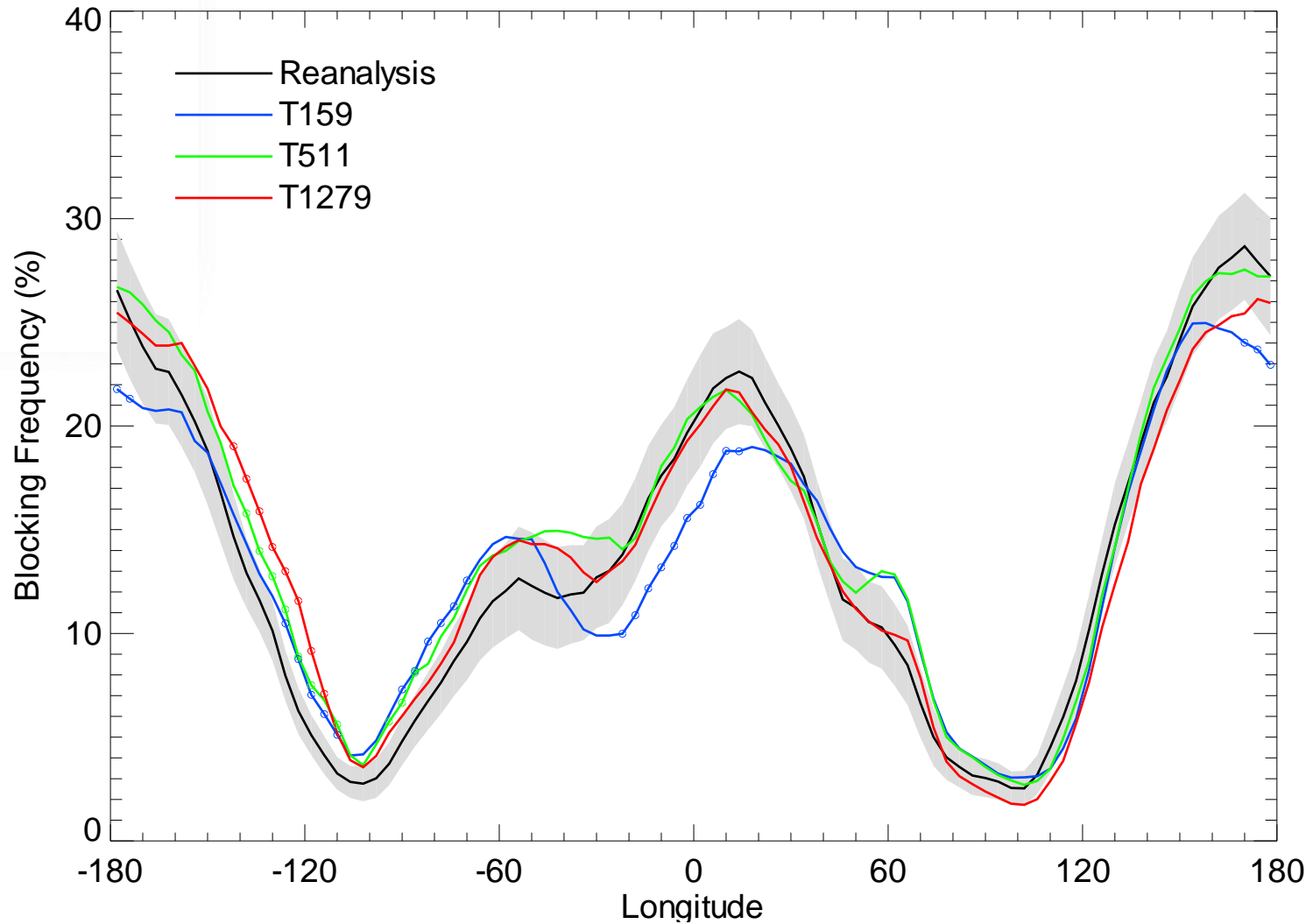


T2047



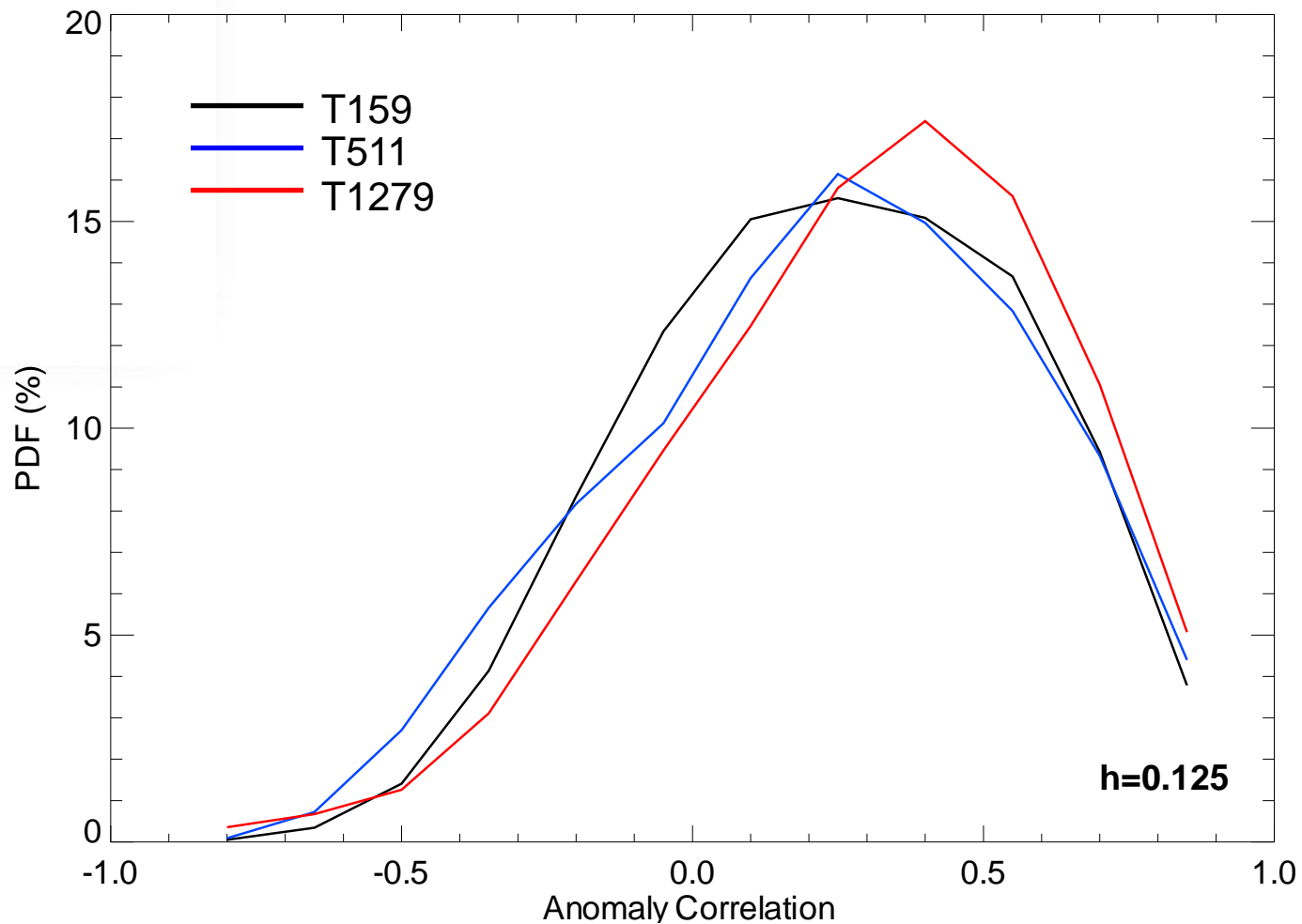
Courtesy of Thomas Jung (ECMWF)

Blocking Frequencies: DJFM 1960-2007



Courtesy of Thomas Jung (ECMWF)

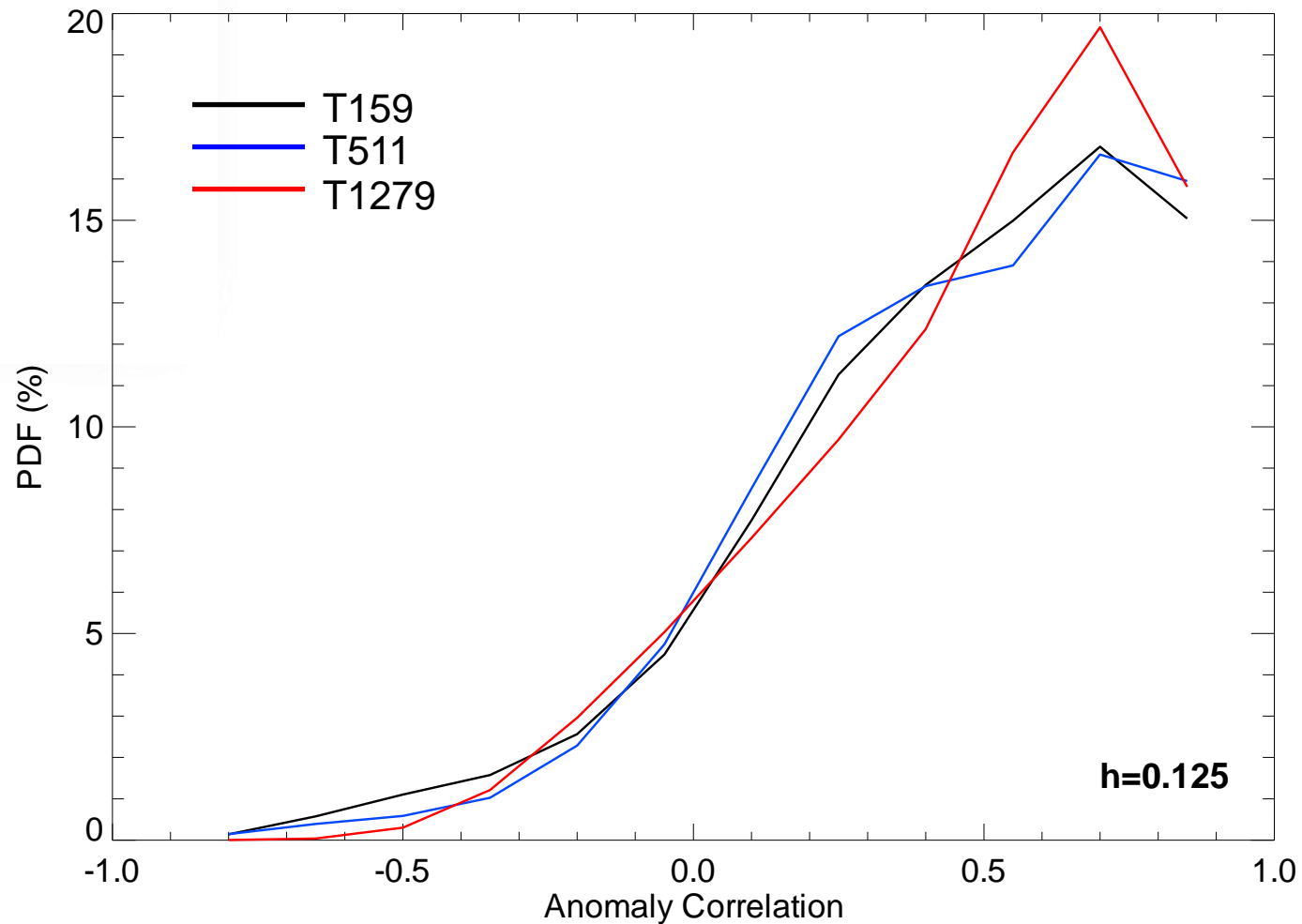
PDF of ACCs: Z500 Anomalies (DJF, NH)



Calibration runs + Ensembles, N=106

Courtesy of Thomas Jung (ECMWF)

PDF of ACCs: X_{200} Anomalies (DJF, Tropics)

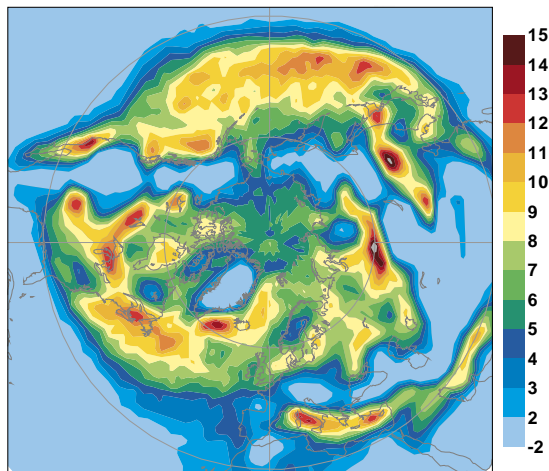


Calibration runs + Ensembles, N=106

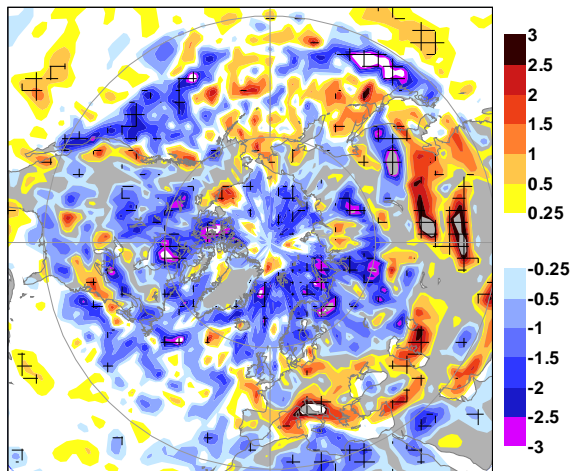
Courtesy of Thomas Jung (ECMWF)

Number of Extratropical Cyclones: DJF 1989-2007

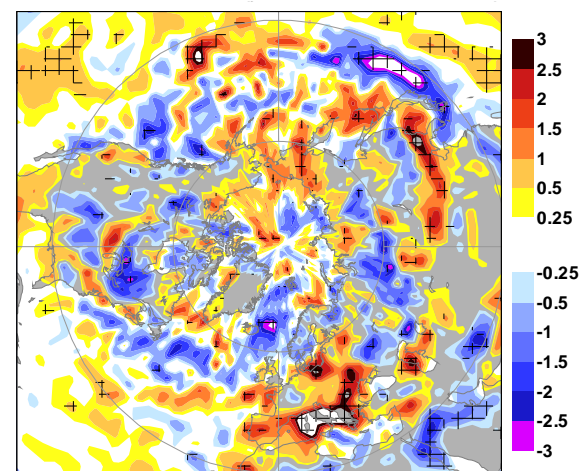
ERA



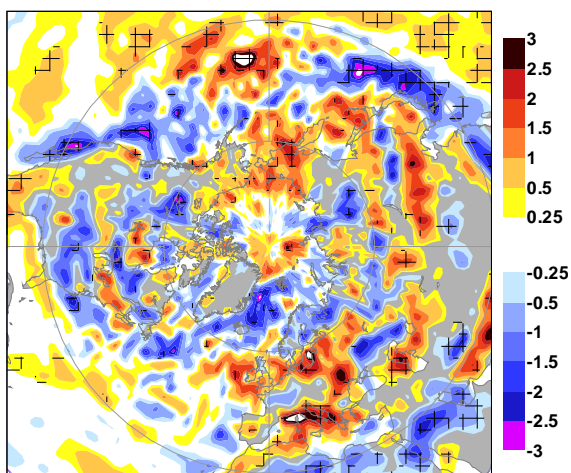
T_L159-ERA



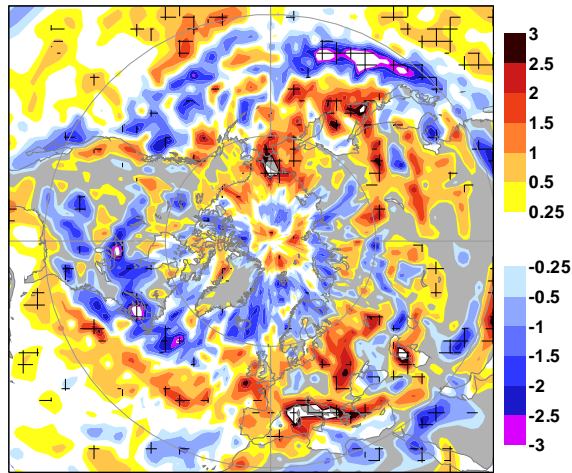
T_L511-ERA



T_L1279-ERA



T_L2047-ERA

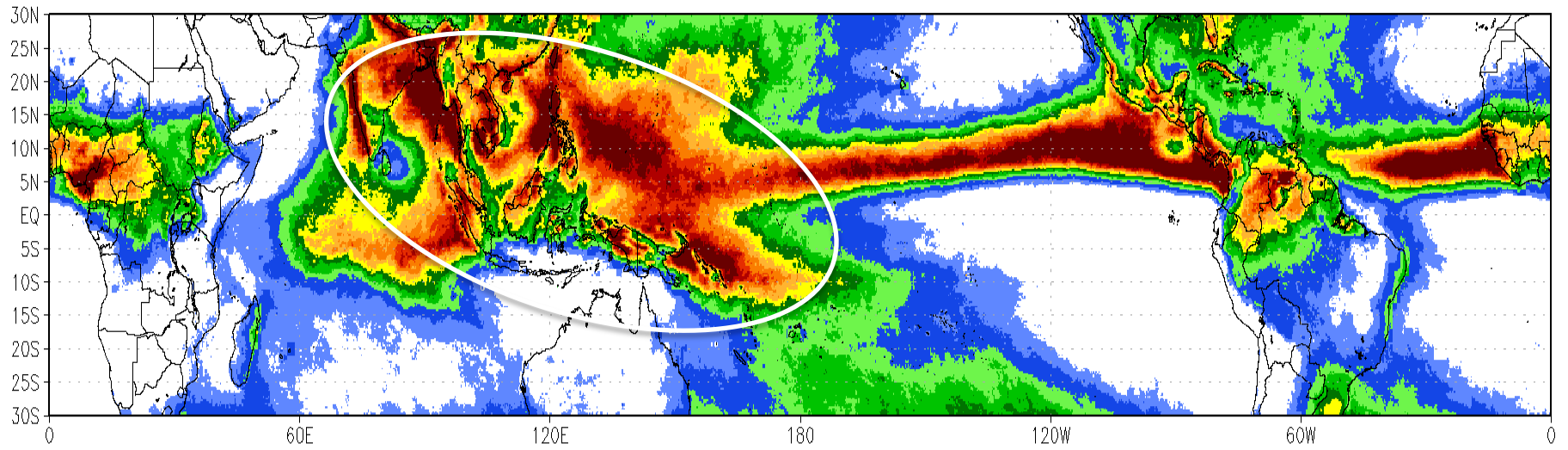


Criteria:

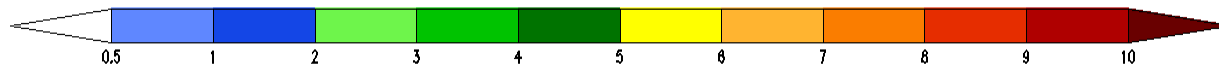
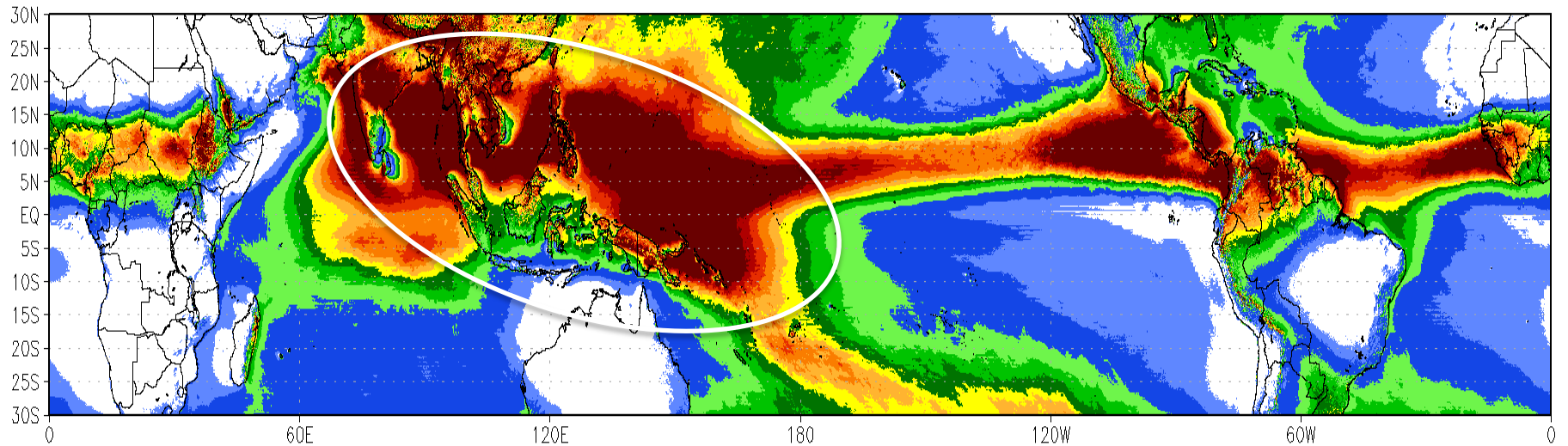
- min lifetime of 2 days
- min migration distance of 1000 km

Courtesy of Thomas Jung (ECMWF)

TRMM JJA Total Precipitation (mm/day)

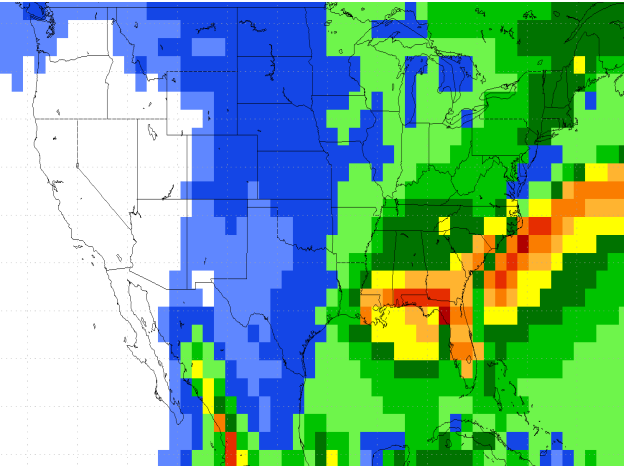


T2047 JJA Total Precipitation (mm/day)

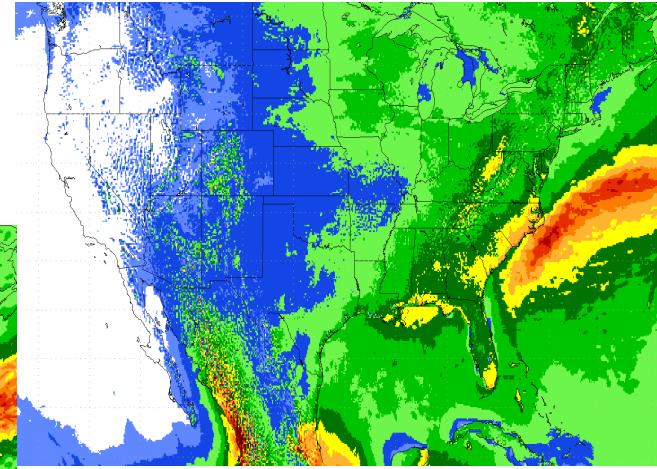


JJA Mean Rainfall (8 seasons)

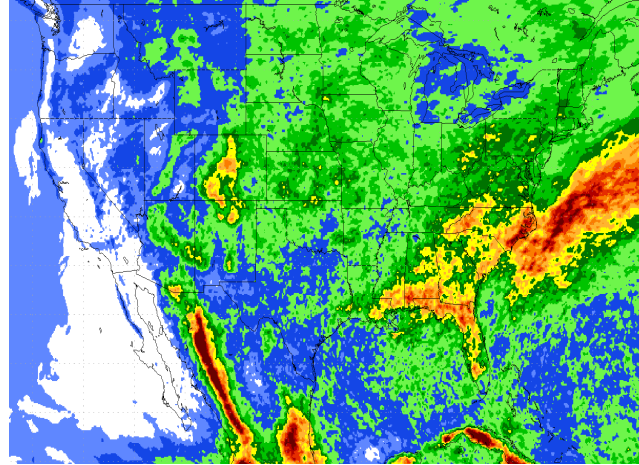
128km: IFS T159



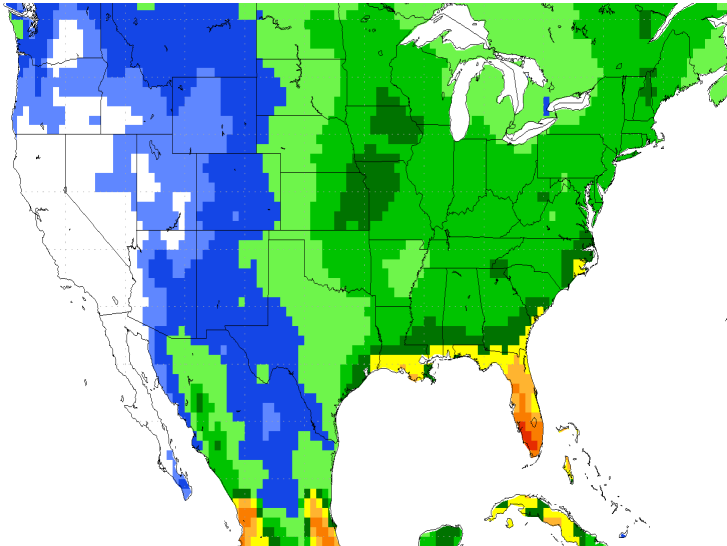
10km: IFS T2047



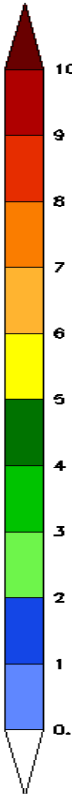
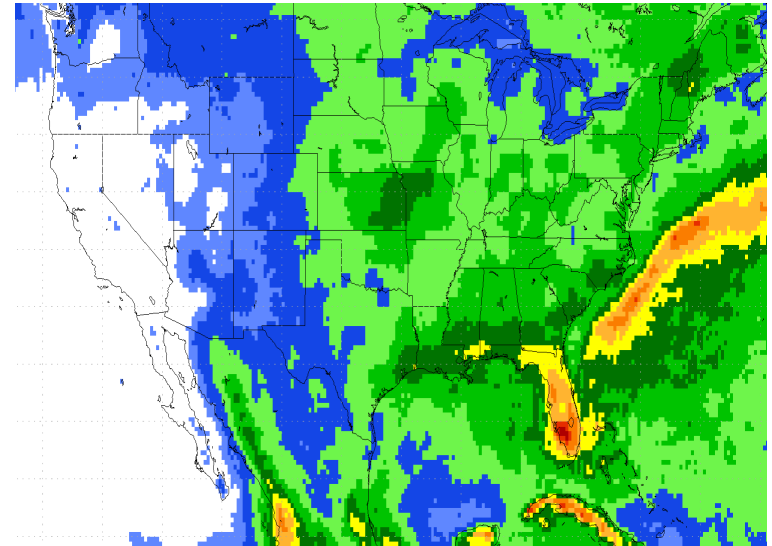
7km: NICAM



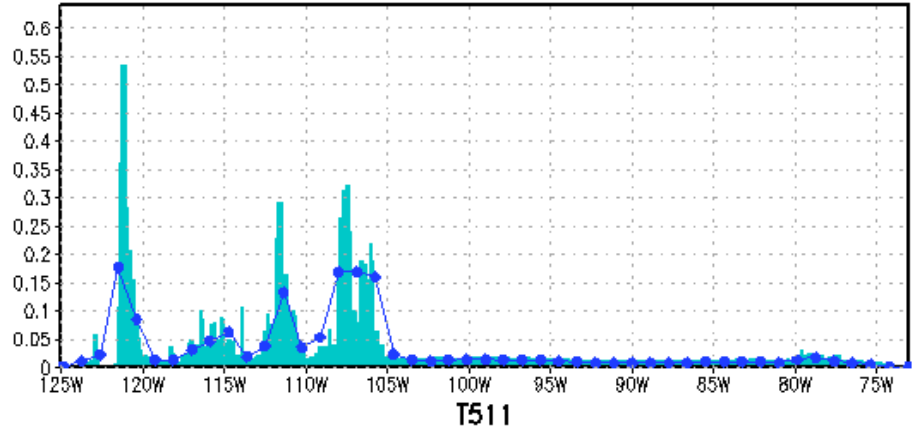
40 km: Chen et al.



25 km: TRMM

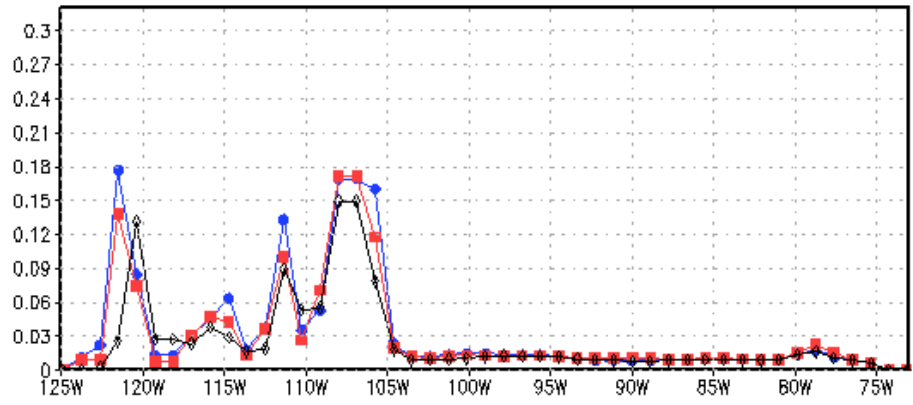
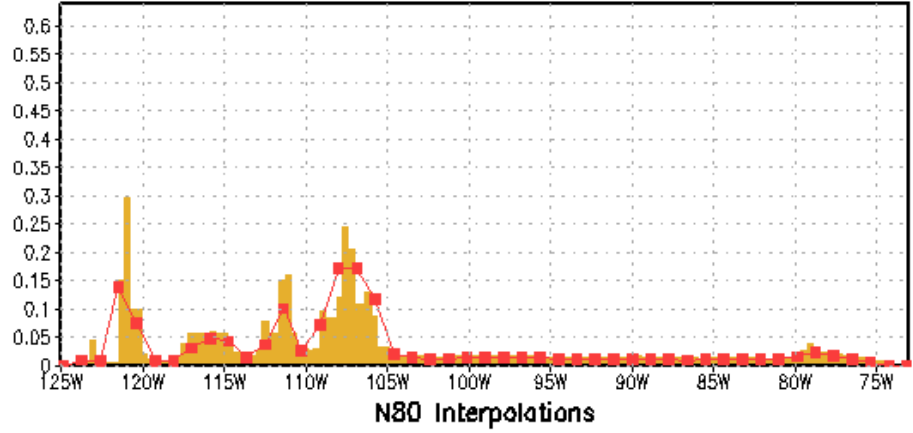


IFS JFM Mean Snow Depth CONUS Transect at 40 N



Interpolated high-resolution
agrees with native T159

Orographic features are not
represented



Courtesy of Paul Dirmeyer



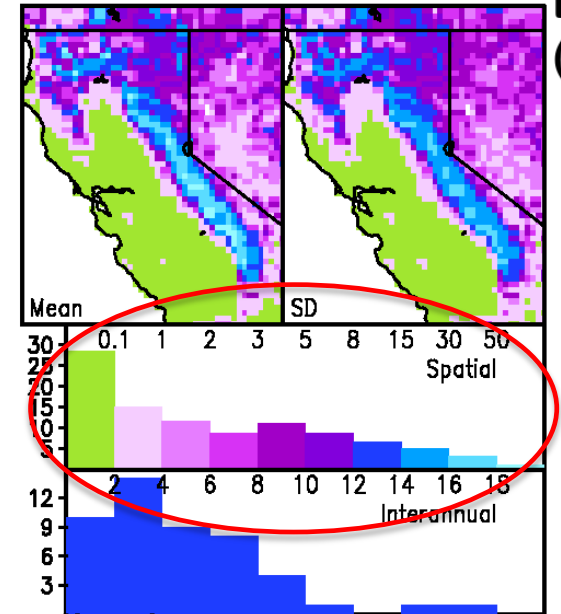
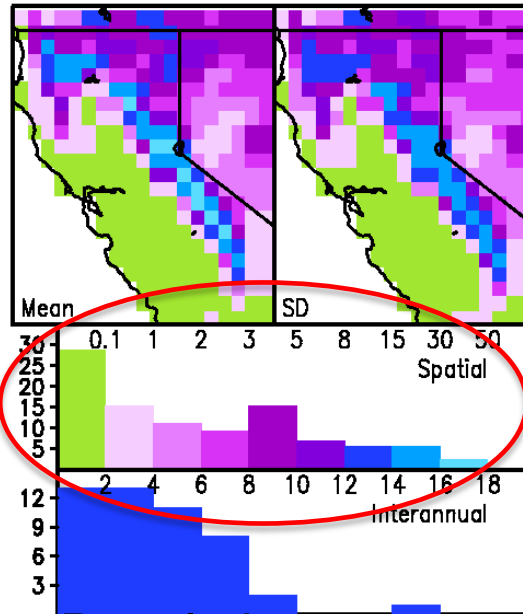
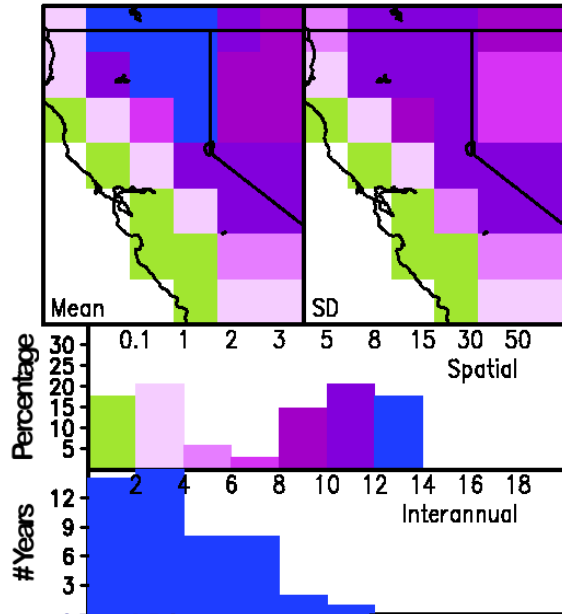
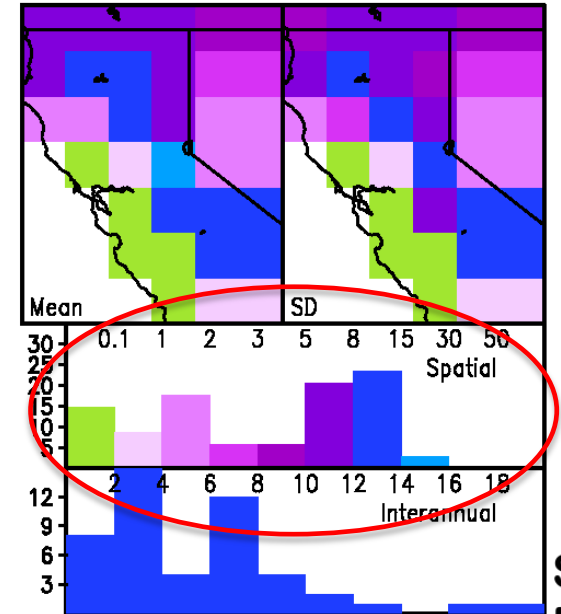
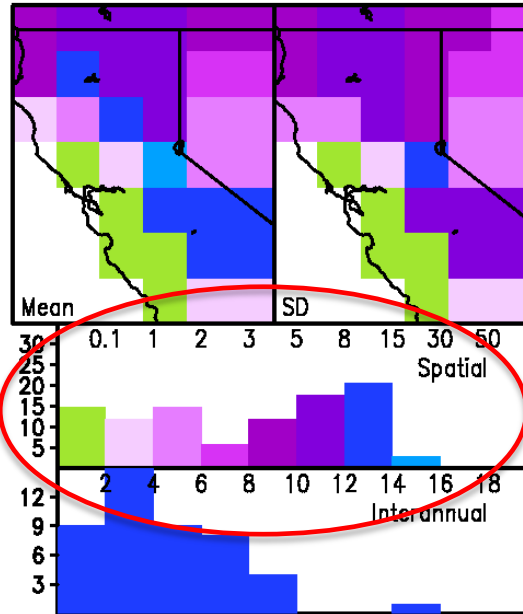
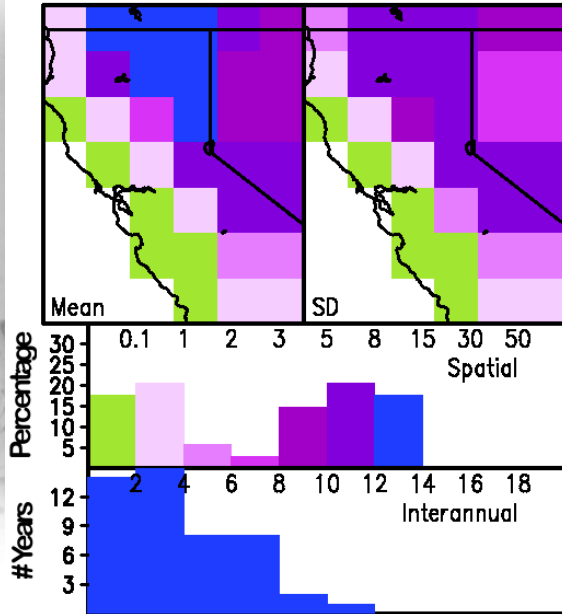
Reduced

Native

T159

T511

T1279



Snow Depth (mm)

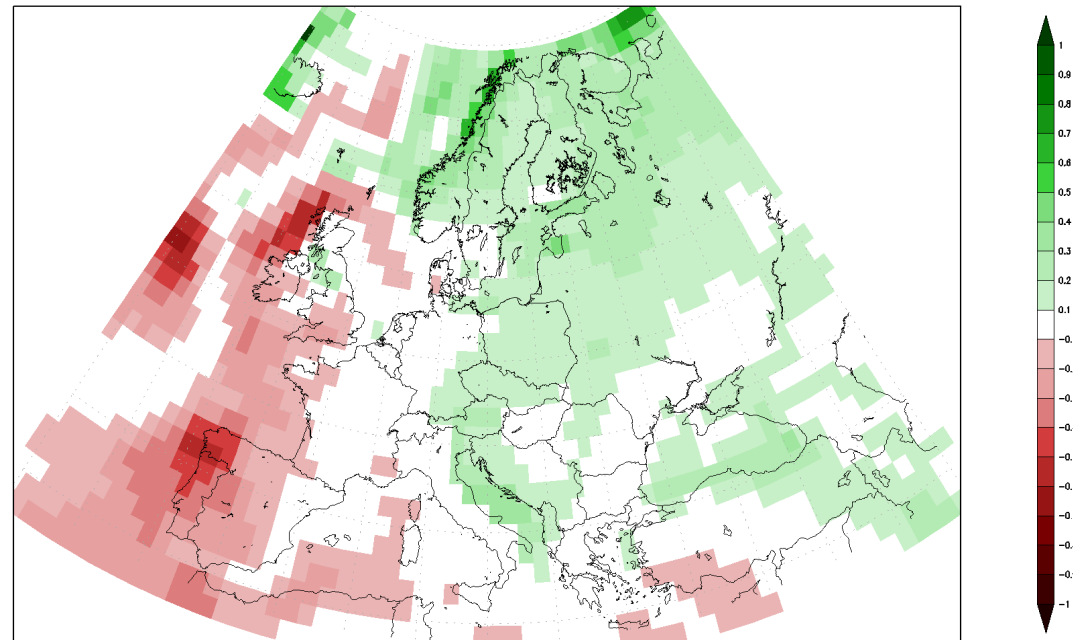
Decreasing Resolution Biases Distribution

Courtesy of Paul Dirmeyer



Time Slice (21st C minus 20th C) Annual Mean Precipitation

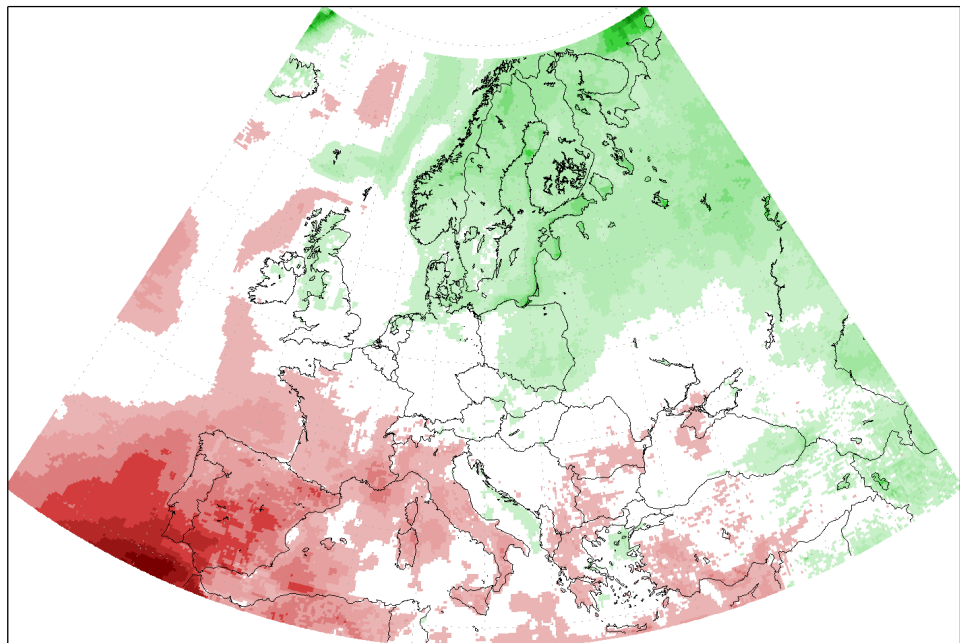
T159 Native Sensitivity of Annual Mean Precipitation (mm/day)



T159

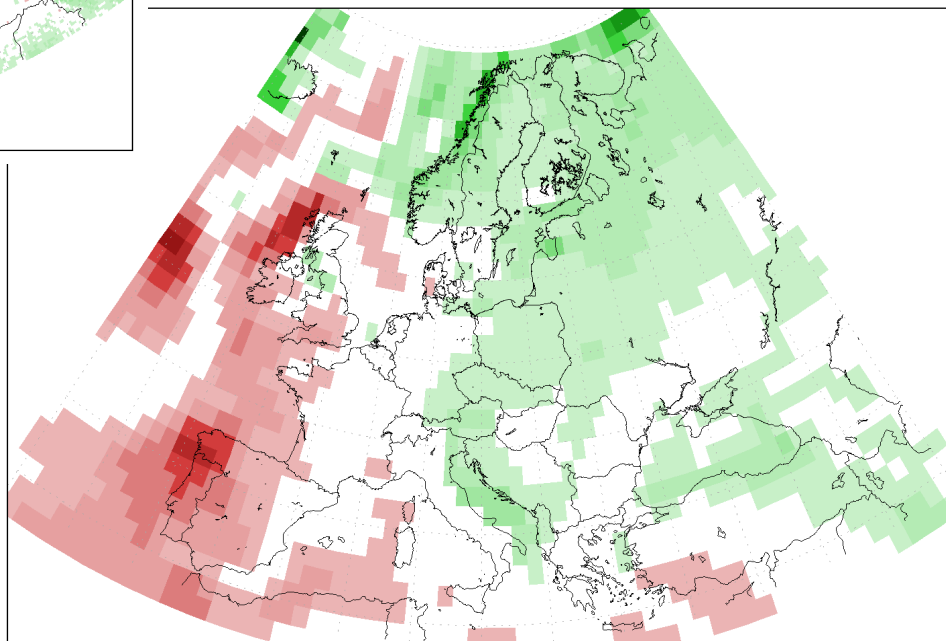
Courtesy of Ben Cash

T1279 Native Sensitivity of Annual Mean Precipitation (% change)



Time Slice (21st C minus 20th C) Annual Mean Precipitation

T159 Native Sensitivity of Annual Mean Precipitation (mm/day)



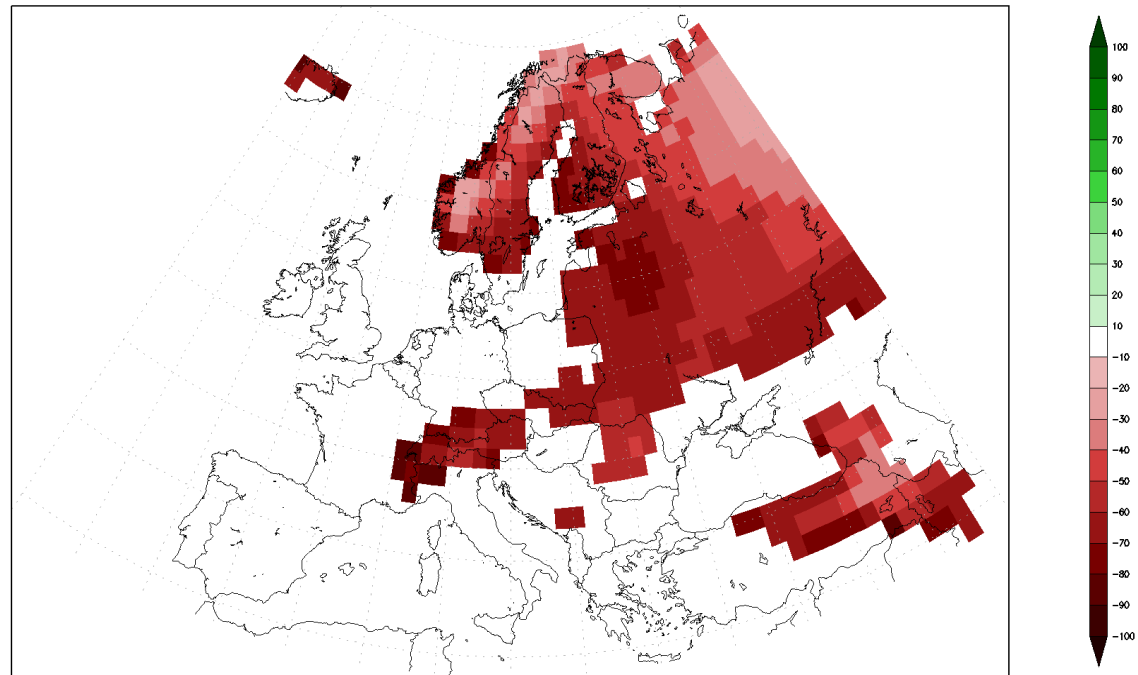
T1279

T159

Courtesy of Ben Cash

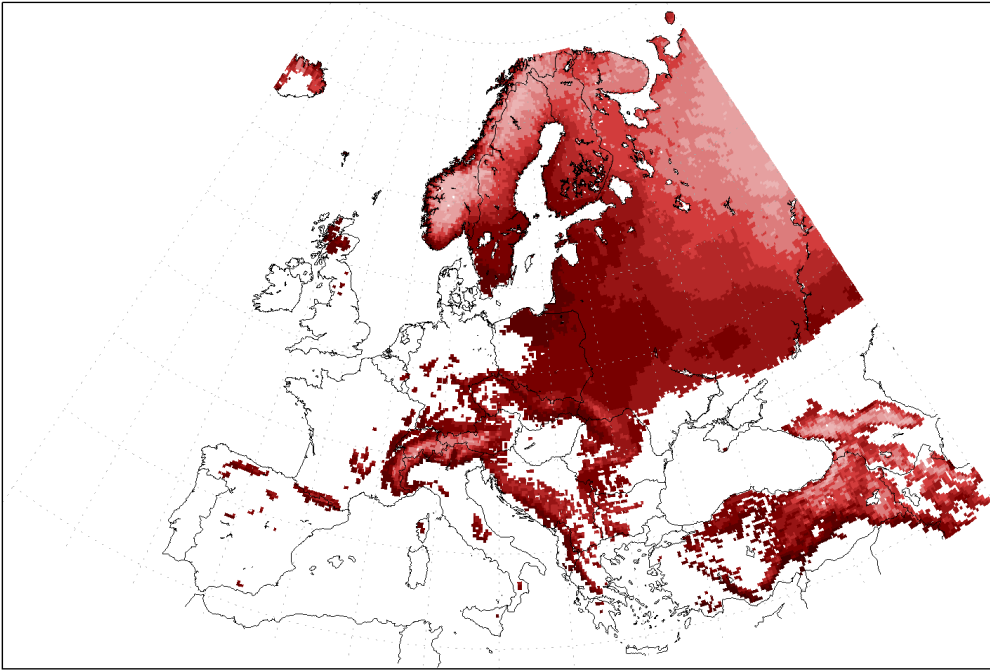
Time Slice (21st C minus 20th C) Annual Snow Depth

T159 Native Sensitivity of Annual Mean Snow Depth (% change)



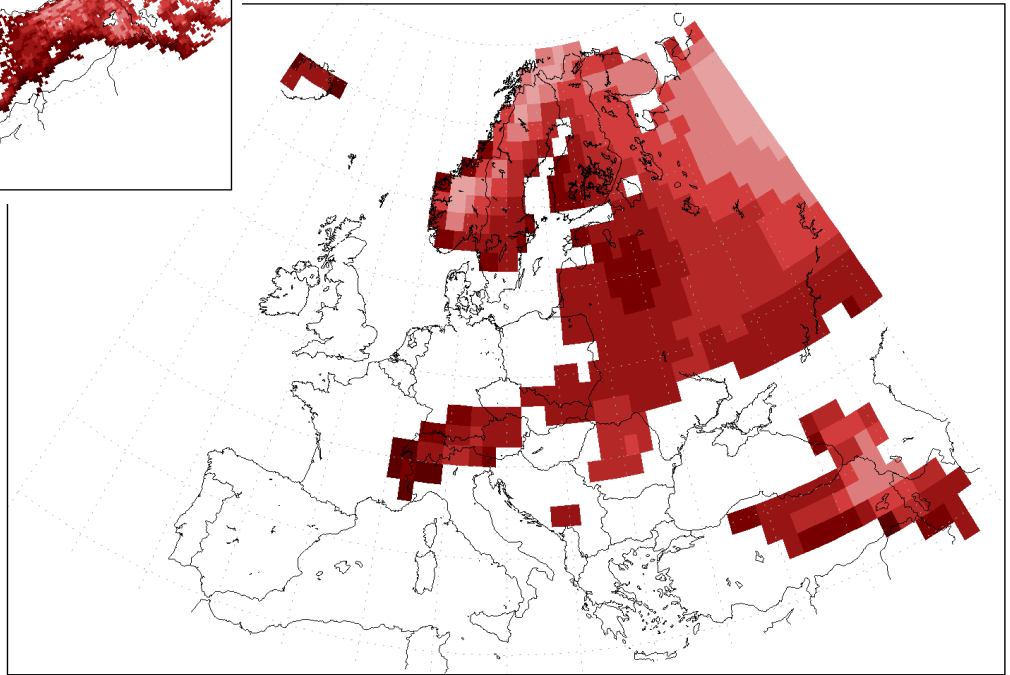
T159

Courtesy of Ben Cash



Time Slice (21st C minus 20th C) Annual Snow Depth

Native Sensitivity of Annual Mean Snow Depth (% change)

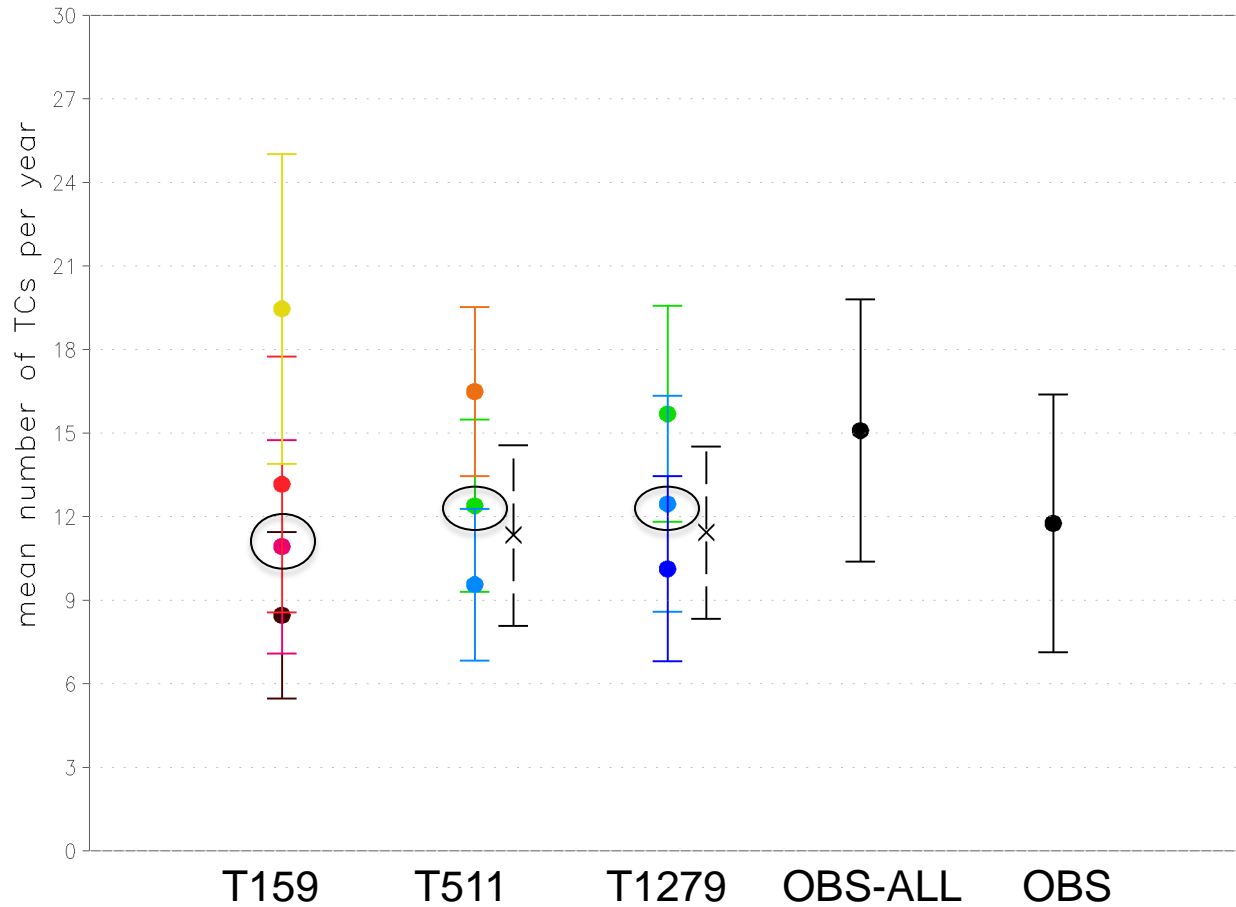


T1279

T159

Courtesy of Ben Cash

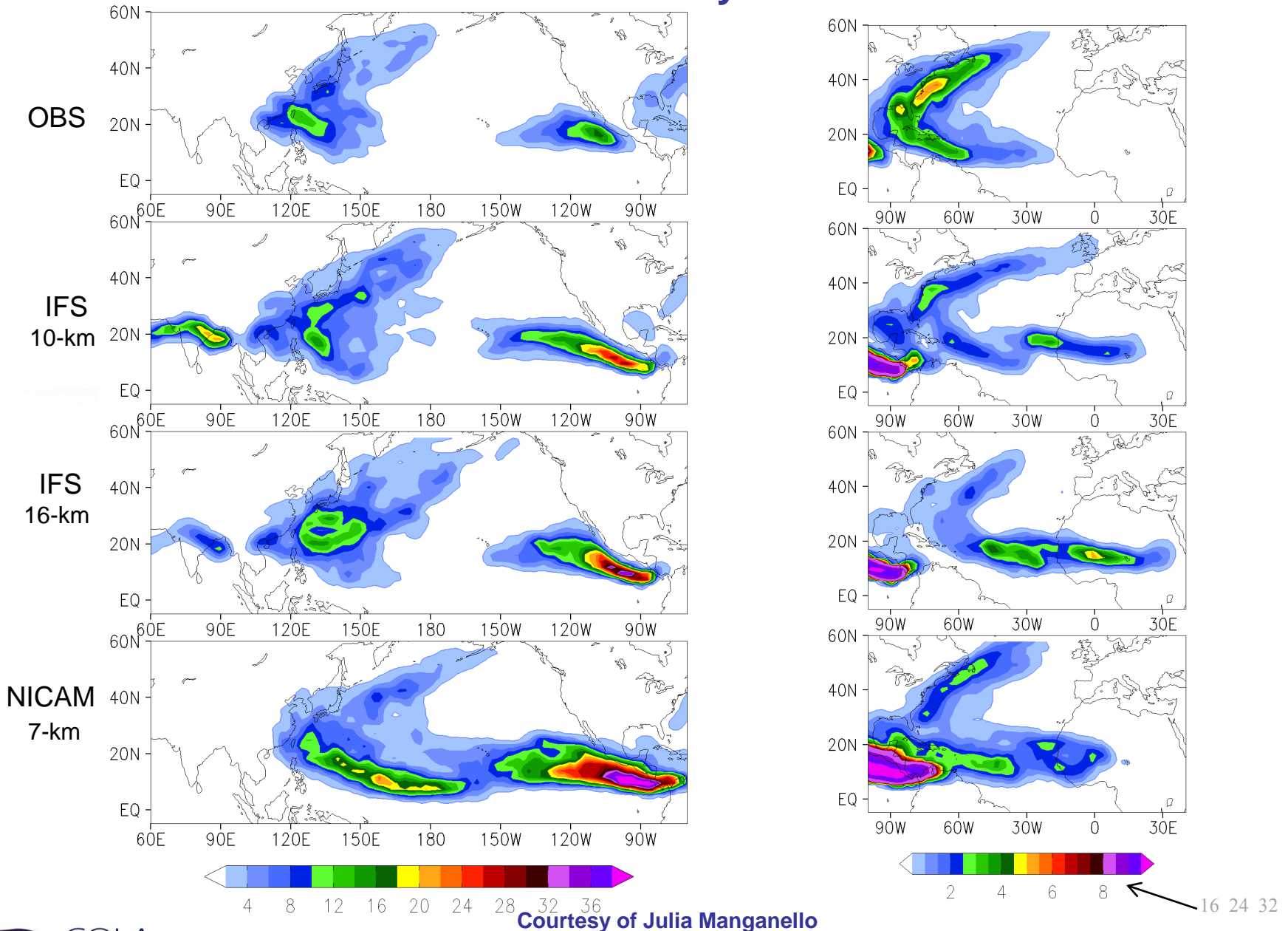
Tracking and Identification of TCs: North Atlantic



— 3/3 — 4/4 — 5/4 — 5/5 —x— SPD, 1/1 — 12/6 — 10/6
— 12/10 — 14/12

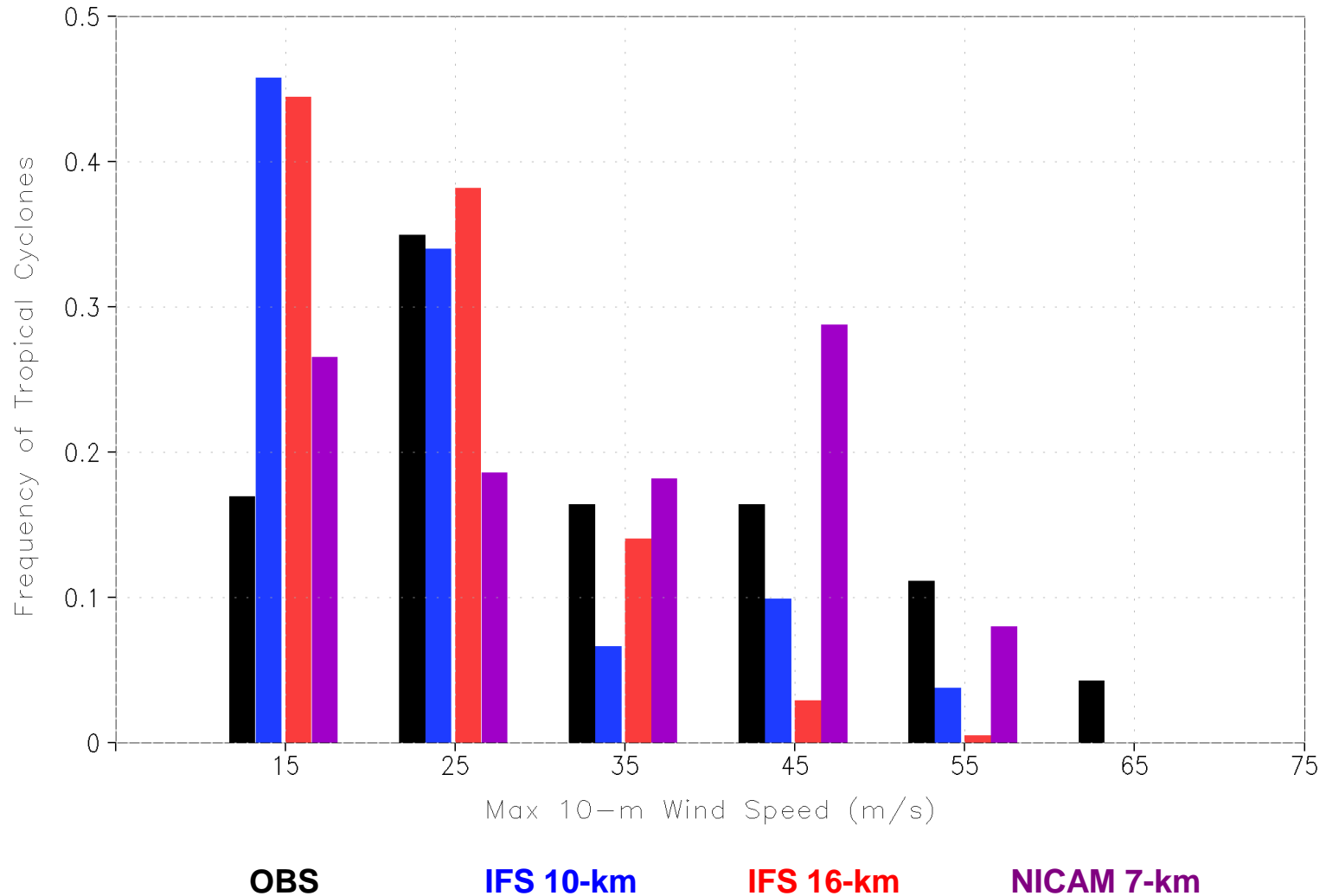
Courtesy of Julia Manganello

Track Density of TCs



Courtesy of Julia Manganello

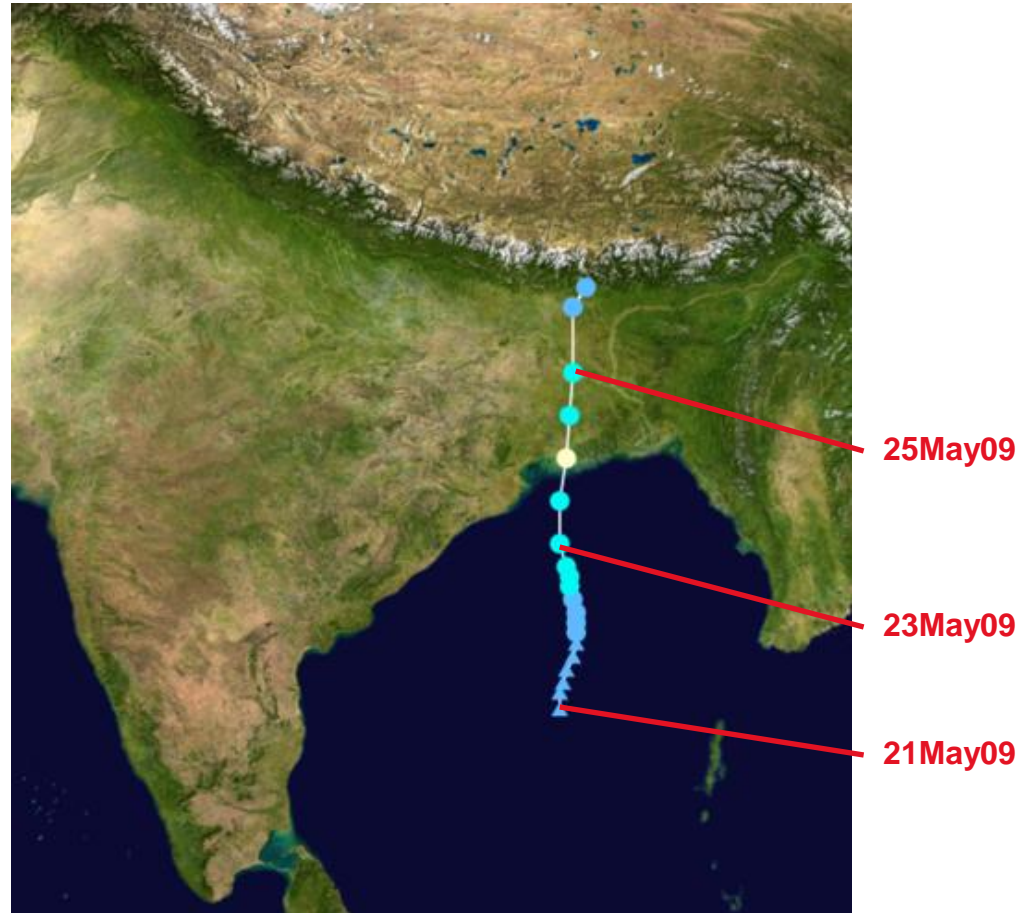
Intensity Distribution of TCs: Northern Hemisphere



Courtesy of Julia Manganello

May 2009 - Tropical Cyclone Aila

Single case example:
NICAM simulation accurately predicted development, evolution and track of TC Aila over 5-day period



Tropical Cyclone Aila made landfall in India on the Bangladesh border region on May 25 as a borderline category 1 hurricane. TC Aila had sustained winds of 65 - 75 mph at landfall. Approximately 150,000 people were left homeless in India, and at least 45 people have died. In Bangladesh, 10,000 people are homeless, and 89 have died with hundreds missing. The death toll is expected to rise.

Credit: NOAA