Challenges and prospects of global high-resolution climate modelling

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Resolution of CMIP3-5 models

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Table 1 Reanalysis and model names and specifications

Official names	Atmosphere		Ocean		References
	Grids (°)	Levels	Y, X points	Levels	
R-2	1.88 × 1.875	28 L			Kanamitsu et al. (2002)
ERA-40	2.50 × 2.5	60 L			Uppala et al. (2005)
ERA-Int	1.50 × 1.5	60 L			Dee et al. (2011)
ACCESS1.0	**1.88 × 1.25**	**38 L**	**300 × 360**	**50 L**	1
BCC–CSM-1	**2.81 × 2.8125**	**26 L**	**232 × 360**	**40 L**	Wu et al. (2010)
CANCM4	**2.81 × 2.8125**	**35 L**	**192 × 256**	**40 L**	2
CCSM4	**0.94 × 1.25**	**26 L**	**320 × 384**	**60 L**	Gent et al. (2011)
CCSM3	*1.40 × 1.4*	*26 L*	*395 × 384*	*40 L*	Collins et al. (2006)
CNRM–CM5	**1.40 × 1.4**	**31 L**	**292 × 362**	**42 L**	Voldoire et al. (2012)
CNRM–CM3	*2.80 × 2.8*	*45 L*	*170 × 180*	*31 L*	Douville et al. (2002)
FGOALS-g2	**2.80 × 2.8**	**26 L**	**196 × 360**	**60 L**	Zhang and Yu (2011)
FGOALS1.0g	*2.80 × 2.8*	*26 L*	*170 × 360*	*33 L*	Yu et al. (2011)
FGOALS-s2	**1.60 × 2.8**	**26 L**	**196 × 360**	**60 L**	3
GISS–E2-H	**2.00 × 2.5**	**40 L**	**180 × 360**	**26 L**	Schmidt et al. (2006)
GISS–EH	*4.00 × 5*	*17 L*	*111 × 180*	*16 L*	4
GISS–E2-R	**2.00 × 2.5**	**40 L**	**180 × 288**	**32 L**	Schmidt et al. (2006)
HadCM3	**2.50 × 3.75**	**19 L**	**144 × 288**	**20 L**	Johns et al. (2006)
UKMO–HadCM3	*2.50 × 3.75*	*19 L*	*143 × 288*	*20 L*	Gordon et al. (2000)
HadGEM2–CC	**1.25 × 1.875**	**38 L**	**216 × 360**	**40 L**	Collins et al. (2008)
UKMO–HadGEM1	*1.25 × 1.875*	*38 L*	*216 × 360*	*40 L*	Johns et al. (2006)
INM–CM4	**1.50 × 2**	**21 L**	**360 × 360**	**40 L**	Volodin et al. (2010)
INM–CM3.0	*4.00 × 5*	*21 L*	*85 × 180*	*33 L*	Diansky and Volodin (2002)
IPSL–CM5A–LR	**1.88 × 3.75**	**39 L**	**149 × 182**	**31 L**	Dufresne et al. (2012)
IPSL–CM4	*2.50 × 3.75*	*19 L*	*149 × 180*	*31 L*	Marti et al. (2010)
MIROC4h	**0.56 × 0.56**	**56 L**	**912 × 1,280**	**47 L**	Mochizuki et al. (2012)
MIROC5	**1.40 × 1.4**	**40 L**	**224 × 256**	**50 L**	Mochizuki et al. (2012)
MIROC3.2	*2.80 × 2.8*	*20 L*	*192 × 256*	*44 L*	Mochizuki et al. (2010)
MIROC–ESM	**2.80 × 2.8**	**80 L**	**256 × 192**	**44 L**	Watanabe et al. (2011)
MIROC–ESM–CHEM	**2.80 × 2.8**	**80 L**	**256 × 192**	**44 L**	Watanabe et al. (2011)
MPI–ESM–LR	**1.88 × 1.875**	**47 L**	**220 × 256**	**40 L**	Giorgetta et al. (2012)
ECHAM5/MPI–OM	*1.88 × 1.875*	*32 L*	*180 × 360*	*40 L*	Roeckner et al. (2006)
MRI–CGCM3	**1.13 × 1.125**	**48 L**	**368 × 360**	**51 L**	5
MRI–GCM2	*2.80 × 2.8*	*30 L*	*111 × 180*	*23 L*	Yukimoto et al. (2000)
NOR–ESM1-M	**1.88 × 2.5**	**26 L**	**384 × 320**	**53 L**	Seland et al. (2008)

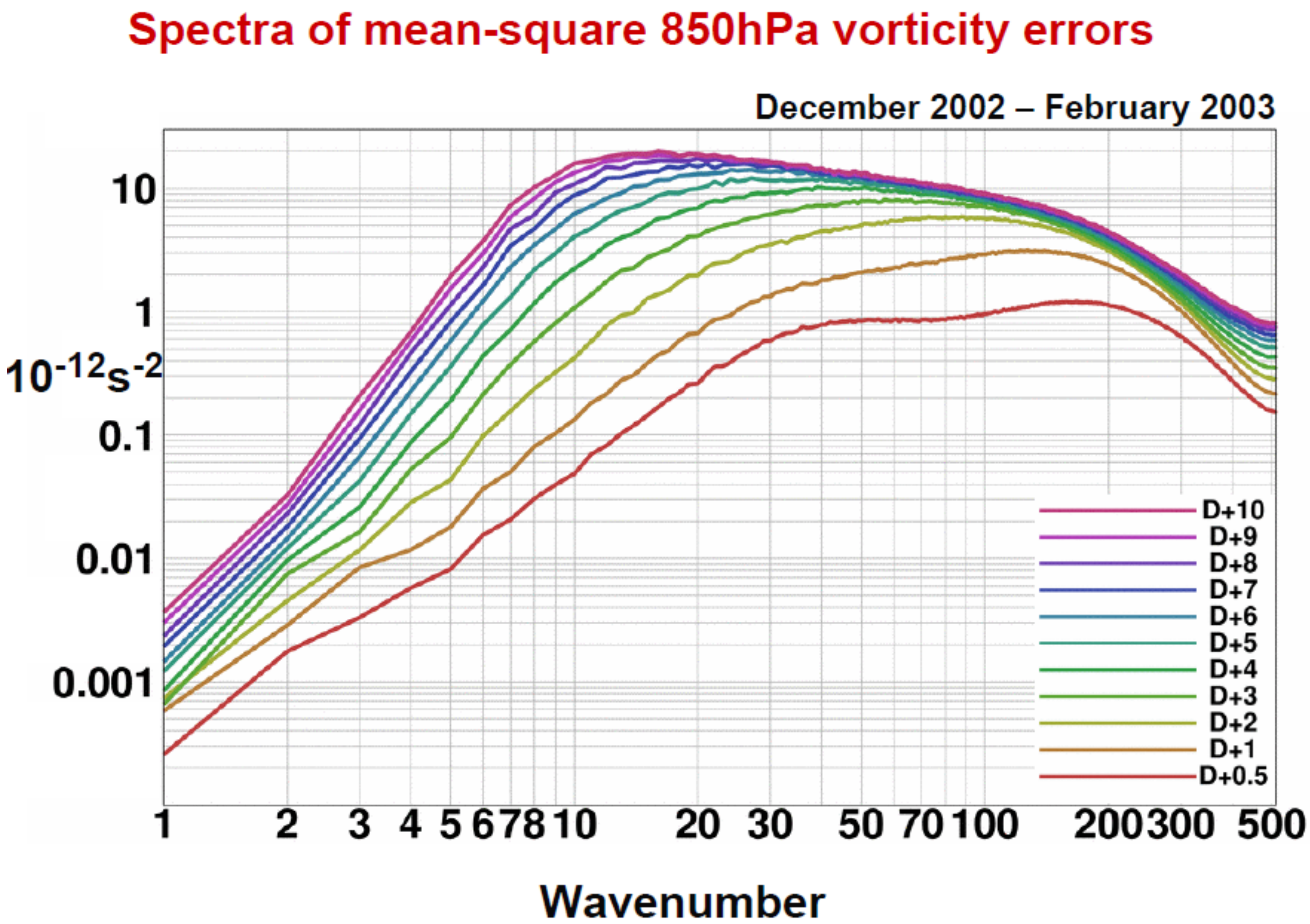
Rows in bold refer to CMIP5 models; those in italics refer to the CMIP3 models that are aligned with the CMIP5 model above

Weare (2013)

Hypotheses

- CORDEX community:
  - Resolution of CMIP5 models too coarse to represent important small-scale features such as complex topography or coastlines
- Global climate modelling community:
  - Accurately resolving meso-scale phenomena → dramatically improved fidelity of the models (mean, variability and extremes)
  - Some of the long-standing model problems can be alleviated

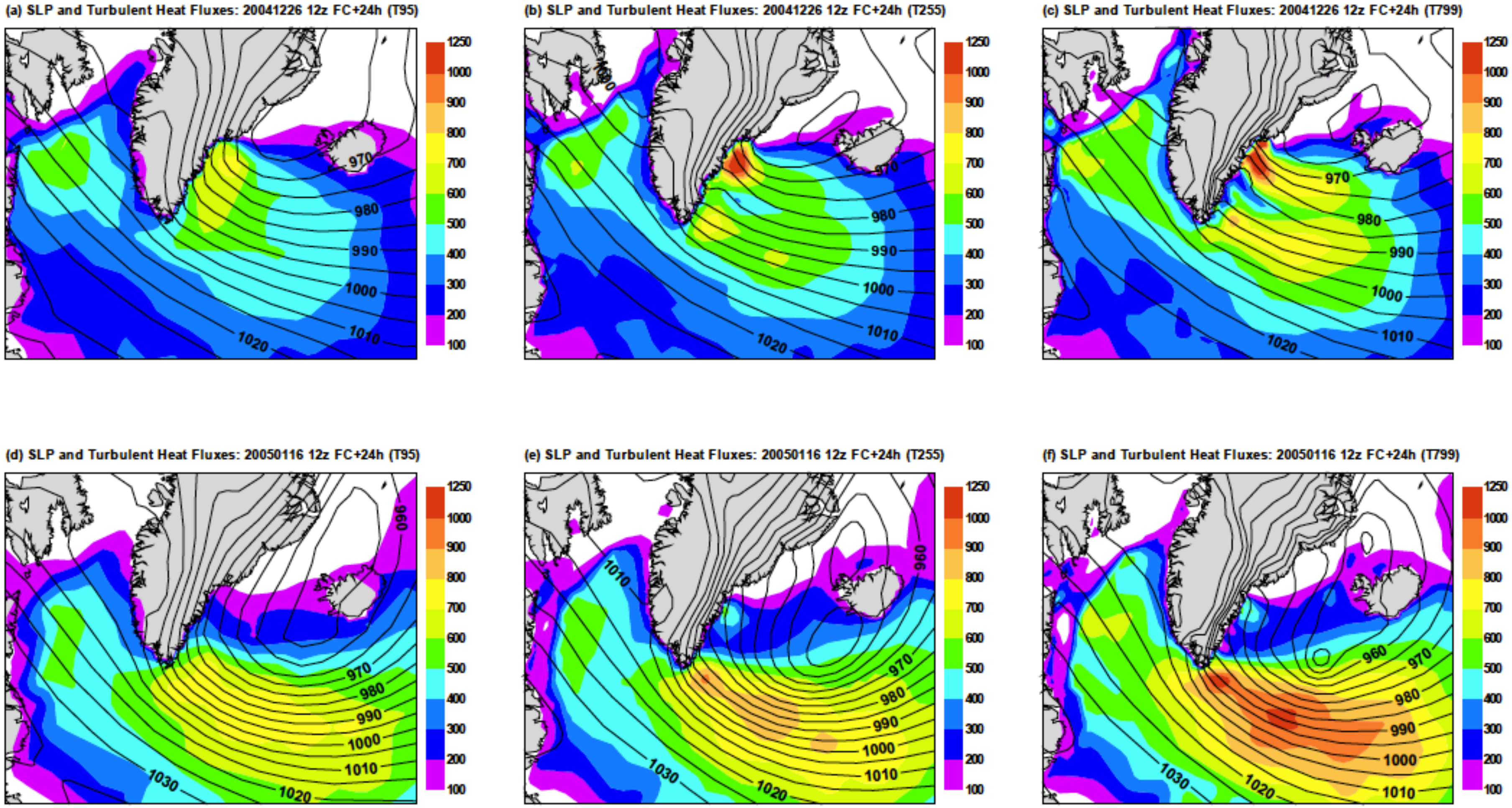
Scale-dependent predictability



Adrian Simmons (ECMWF)

Example: Greenland tip jet

Resolution: 180km | **Resolution: 80km** | **Resolution: 25km**



Jung and Rhines (2007), *J. Atmos. Sci.*

Project Athena

- One of the most comprehensive attempts so far to explore the role of horizontal resolution in climate modelling
- International project: 30 people, in 6 groups from 3 continents
- Two state-of-the-art global AGCMs at the highest possible spatial resolutions
- Dedicated supercomputer at NICS:
  - Cray XT-4 *Athena* (≈20.000 cores)
  - Access from October 2009 – March 2010
  - A total of 80 MCPUh
  - A total of ≈1.2 PB of data (≈ 1/3 of the total CMIP5 archive)

Experiments

IFS experiments	T159	T511	T1279	T2047
Resolution (km)	125	40	15	10
Radiation grid	T63	T159	T511	T639
Time step (min)	60	15	10	7.5
3-month[1]	2001-2009	–	2001-2009	–
13-months[2]	1960-2007	1960-2007	1960-2007	1989-2007
AMIP[3]	1960-2007	–	1960-2007	–
Time slice[4]	2070-2117	–	2070-2117	–
Seasonal forecasts[5]	Sel. cases	–	Sel. cases	–

[1] Forecasts started on 21 May covering June-August.
[2] Forecasts started on 1 November.
[3] Forecast started on 1 November 1960.
[4] More details below.
[5] 10 member lagged ensemble (see below).

NICAM experiments	8 km	8 summers	21 May-30 Aug 2001-2009

Reminder: Philosophy of Project Athena

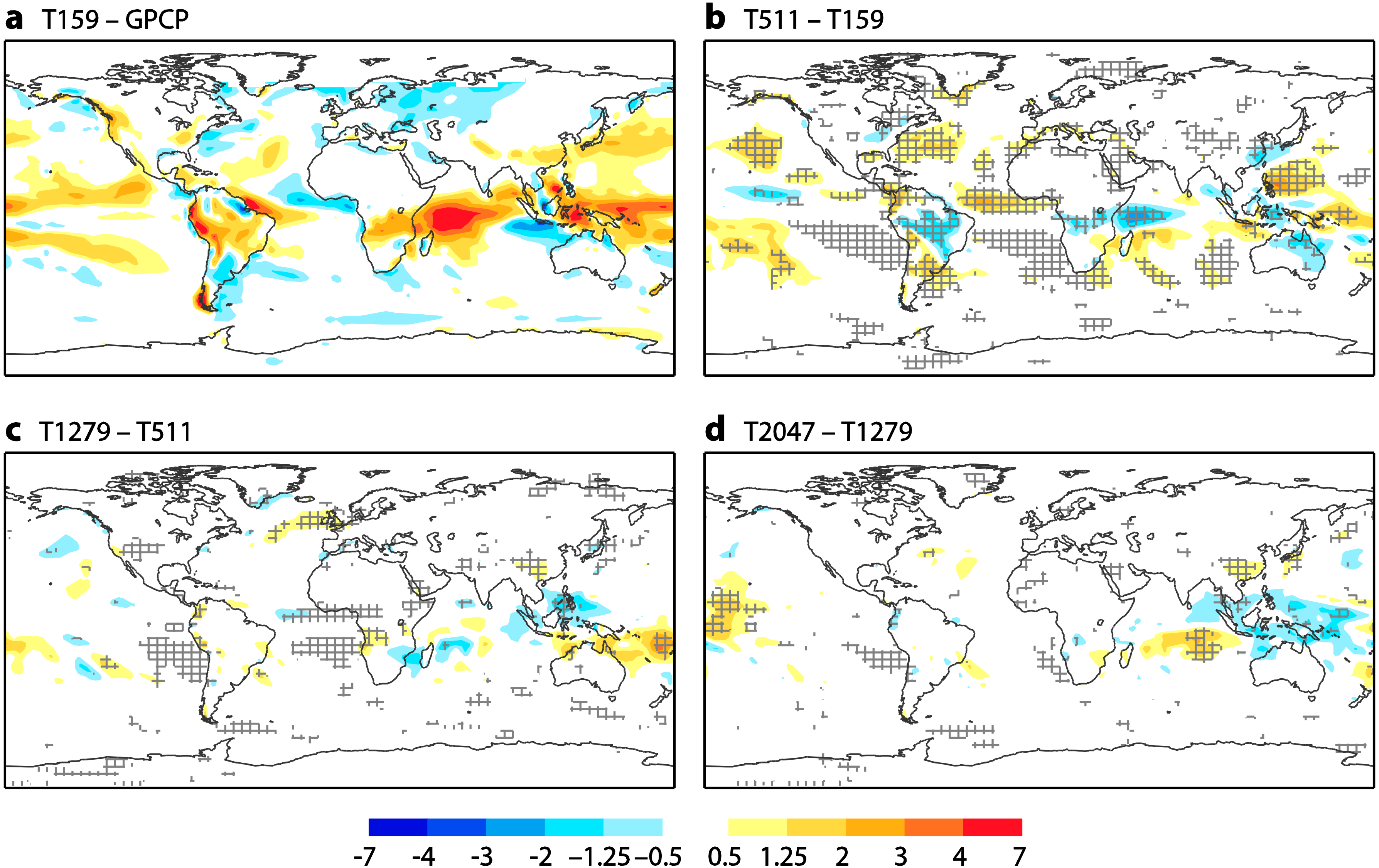
Suspects (causes):
- Convection
- Orographic effects
- Physical processes in extratropical cyclones
- Fronts
- PV filaments

„Climate“ biases (symptoms):
- Westerly wind bias
- Euro-Atlantic blocking
- Storm tracks
- Madden-Julian Oscillation
- Indian Summer Monsoon
- Tropical hydrological cycle

10 15 40 125

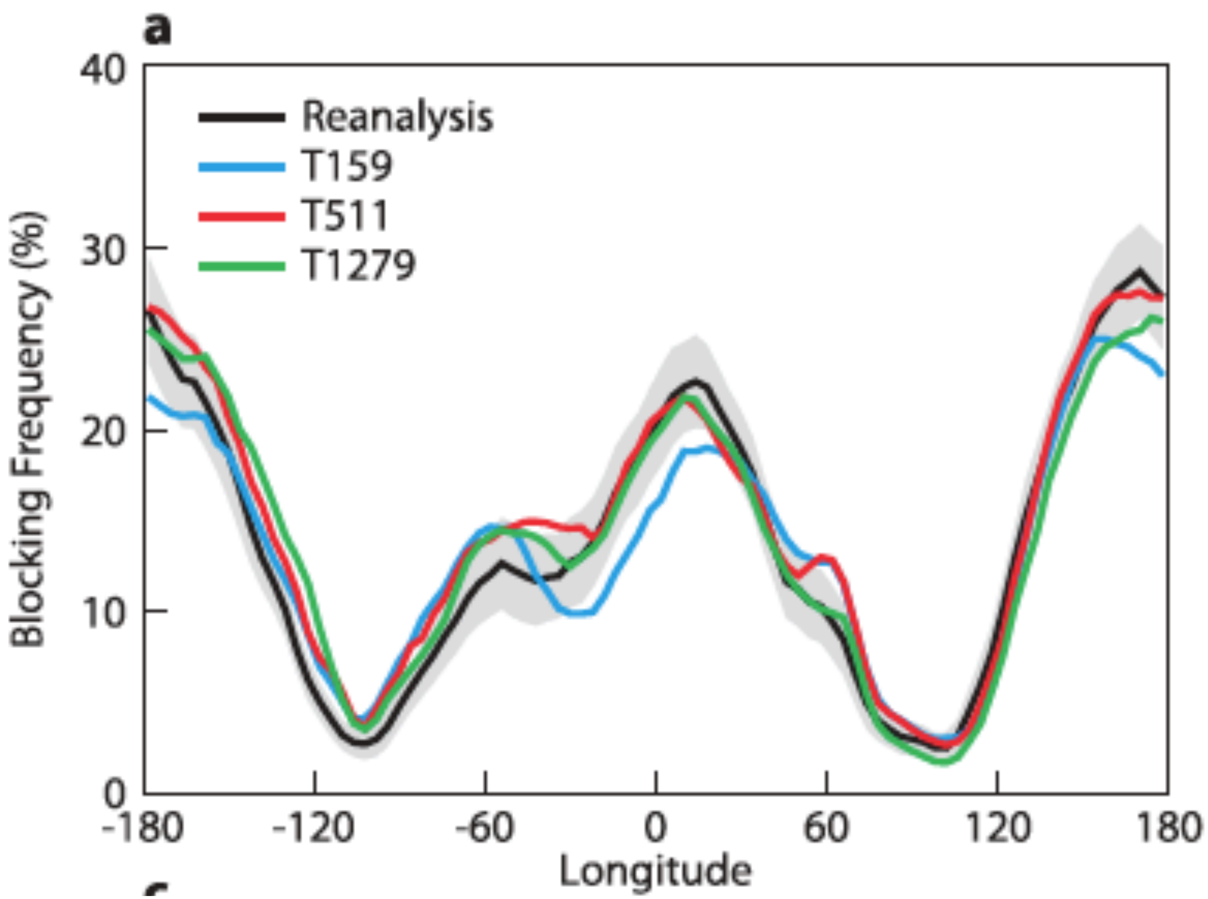
Spatial scale (km)

Precipitation



Jung et al. (2012), *J. Climate*

Northern Hemisphere blocking



Jung et al. (2012), *J. Climate*

Northern Hemisphere blocking

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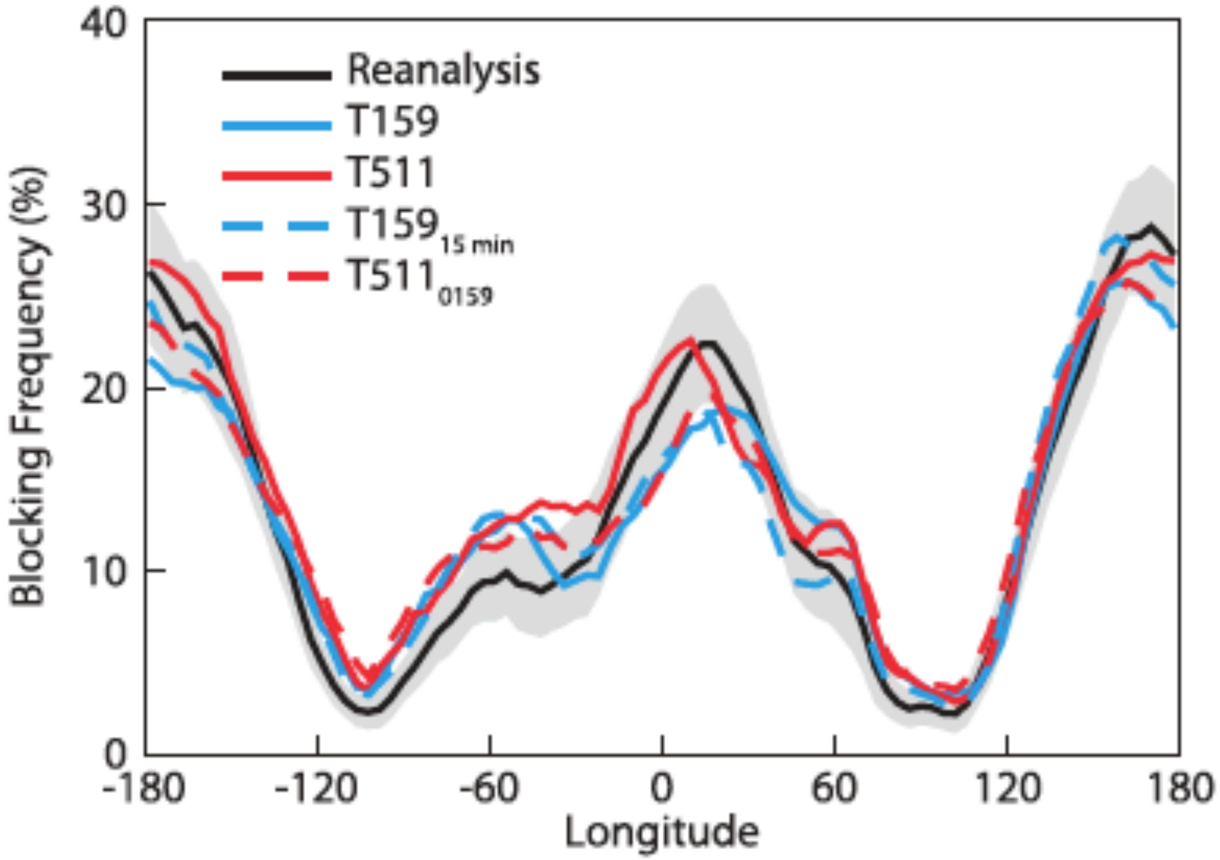

Jung et al. (2012), *J. Climate*

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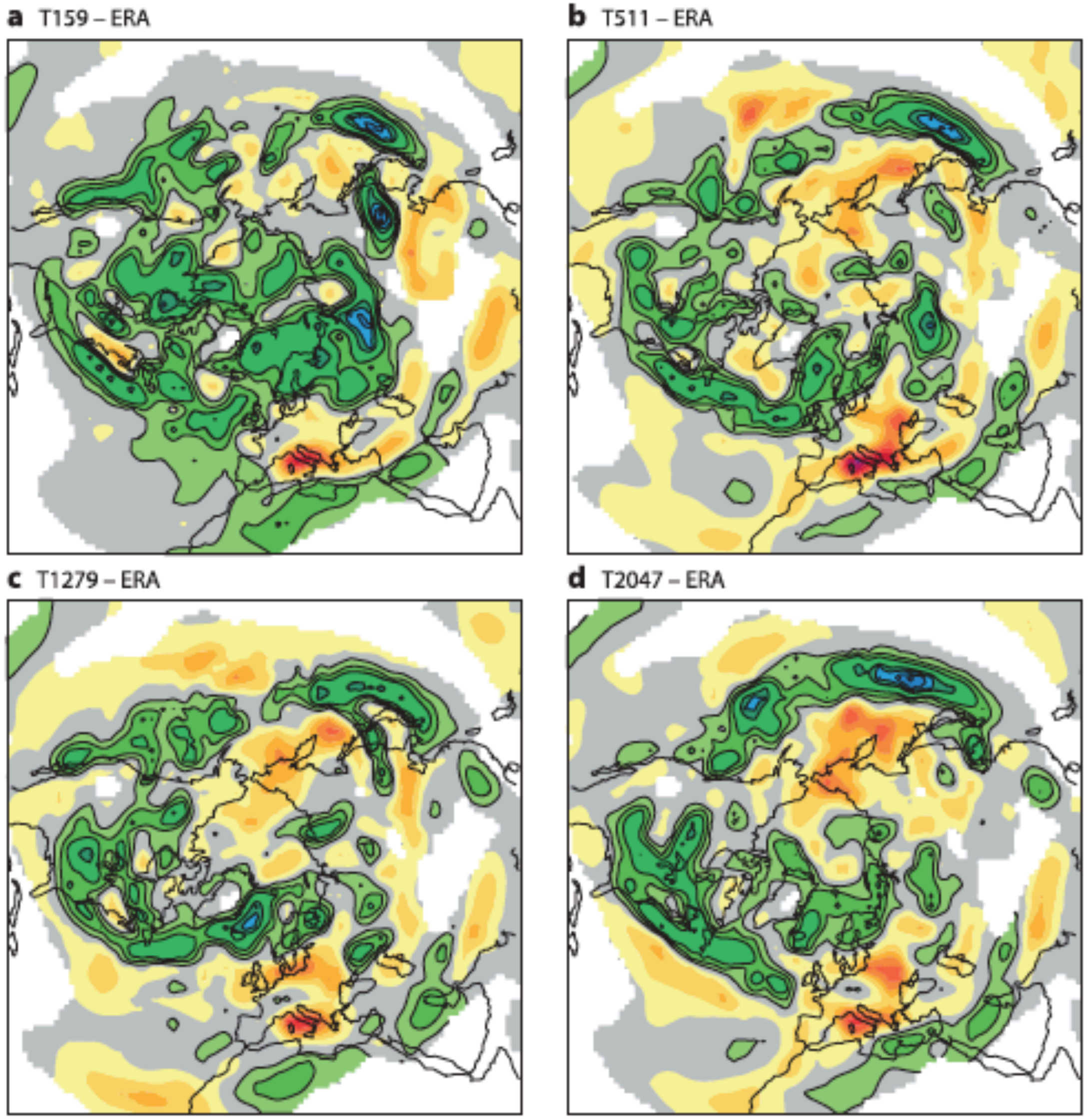
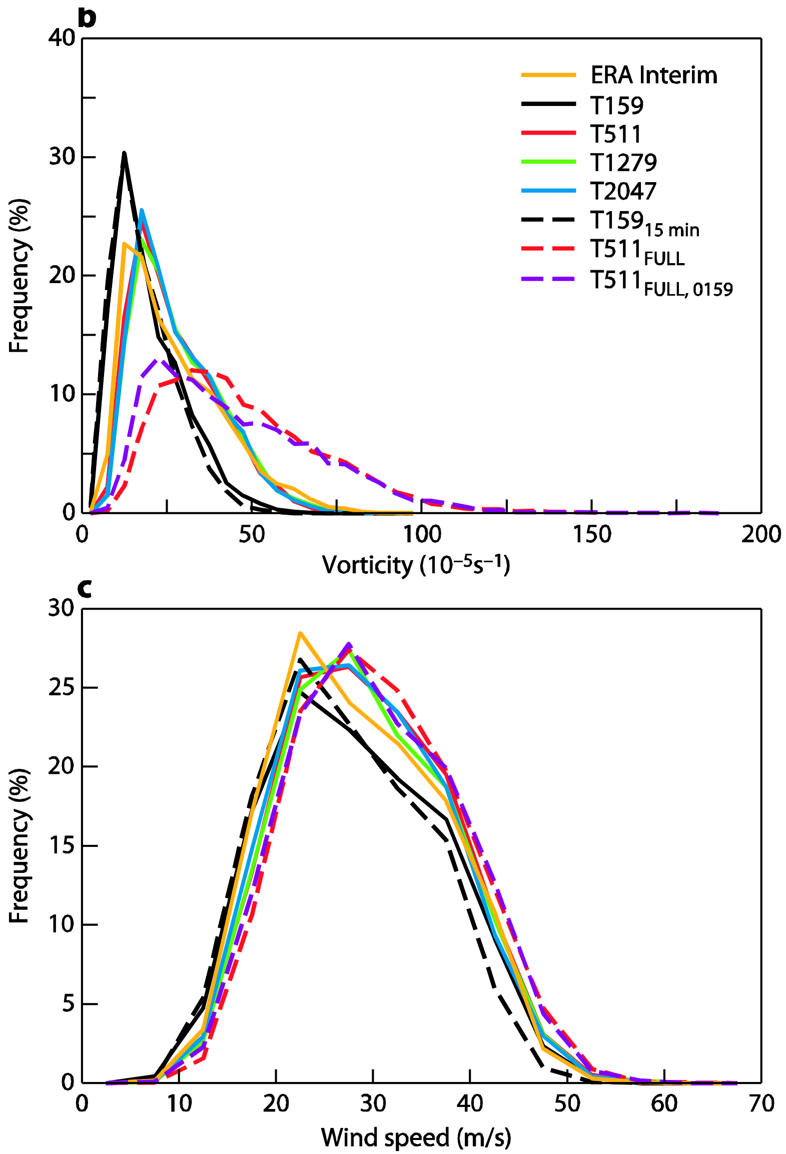
Extratropical cyclones



- Min. lifetime ≥ 2 days
- Min. migration distance ≥ 2000km
- Data truncated to T159/N80

Jung et al. (2012), *J. Climate*

Extratropical cyclones



Jung et al. (2012), *J. Climate*

Madden-Julian Oscillation

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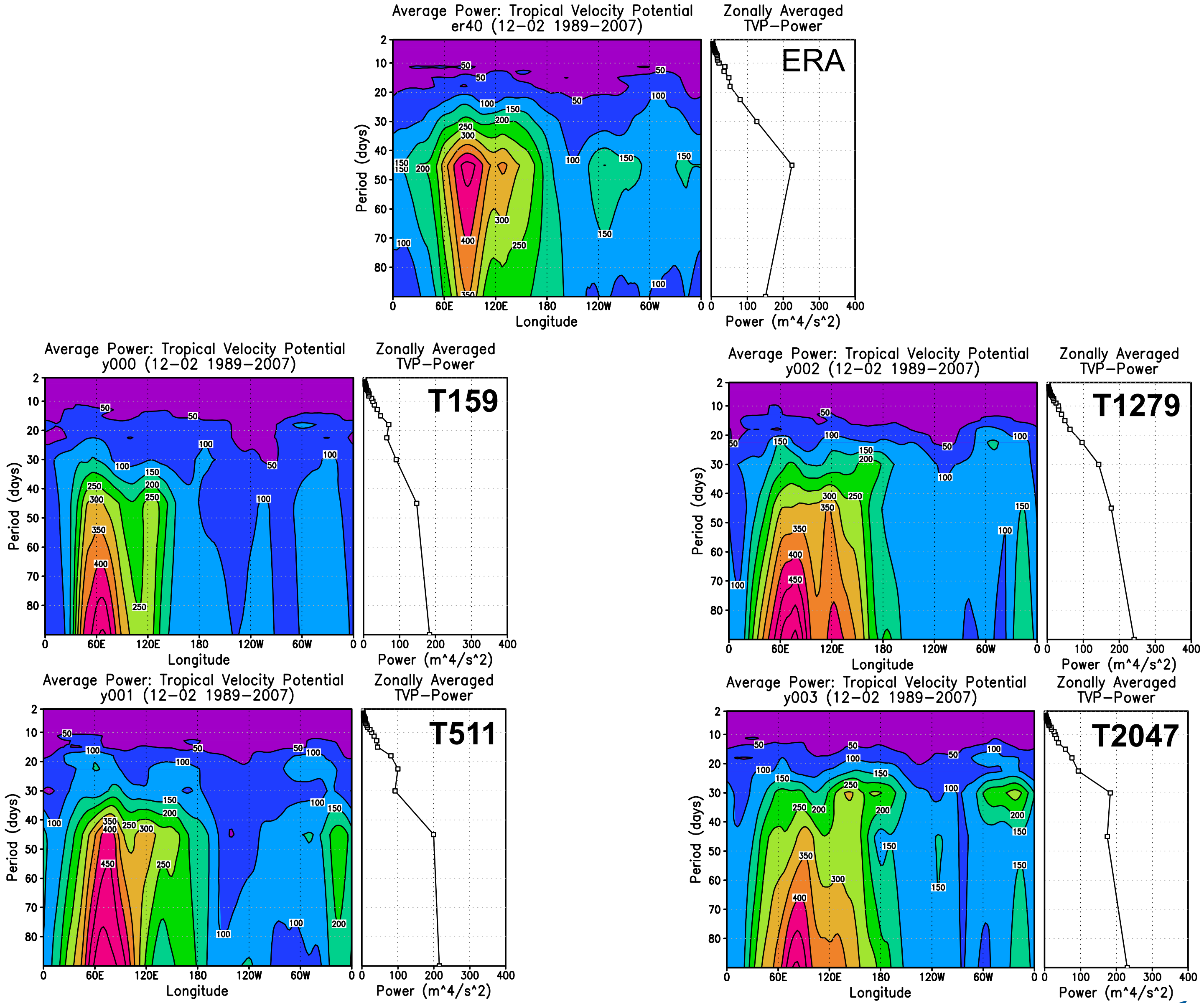

Jung et al. (2012), *J. Climate*

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Atlantic Hurricanes

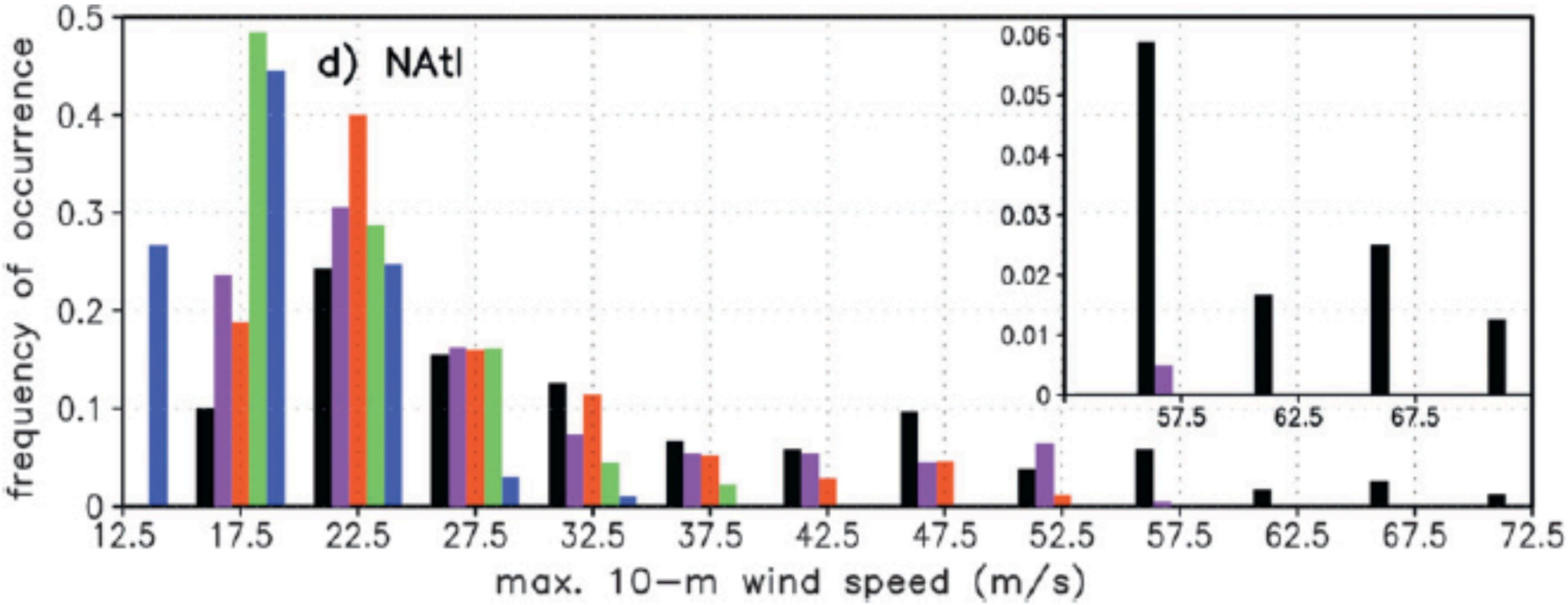
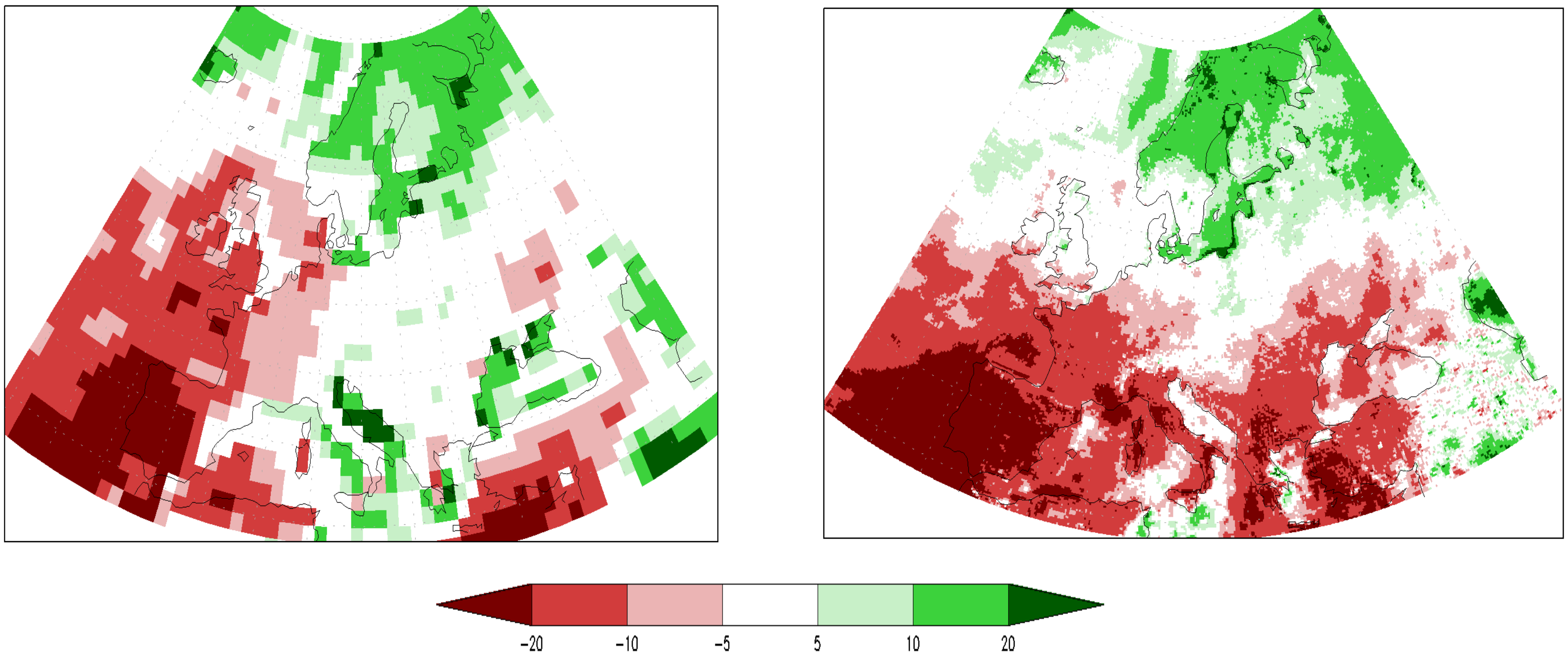


FIG. 4. Distribution of maximum attained 10-m wind speed in the (a) Northern Hemisphere, (b) northwest Pacific, (c) northeast Pacific, and (d) North Atlantic TCs from the IBTrACS data (black bar), IFS T2047 (purple bar), T1279 (red bar), T511 (green bar), and T159 (blue bar) for MJJASON of 1990–2008. Inset plots show the tail of the distributions.

Manganello et al. (2012), *J. Climate*

European precipitation change (Apr-Oct)

T159 (125-km) T1279 (16-km)



Kinter et al. (2013), *Bull. Amer. Meteor. Soc.*

Summary

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- Project Athena very successful from a computational point of view
- Example of successful international collaboration
- Scientific key results:
  - Clear improvement in simulating small-scale features (e.g. tropical cyclones, topographically modified winds)
  - Benefit for large-scale aspects less obvious from Athena results
    - Some improvements (eg tropical precipitation, Euro-Atlantic blocking)
    - Improvements primarily when going from 120 to 40 km
    - Mostly neutral (eg MJO and Indian Summer Monsoon)
    - Some deteriorations (eg QBO and stratospheric temperatures)
  - Time slice experiments: Similar large-scale response but large regional differences

Conclusions

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- Resolution studies with global models would benefit from a more systematic approach
  - international coordination
  - Define a suite of experiments at various resolutions (from NWP to projections)
- Close collaboration with model developers (grey zone issues, parametrization tuning)
- More research needed to understand the inverse energy cascade in the 10-500 km scale range
- More diagnostic studies required to evaluate meso-scale phenomena in Athena-type experiments
- Access to full data set required−ideally with processing capabilities

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