Characteristics of gravity waves from convection using idealized model simulations

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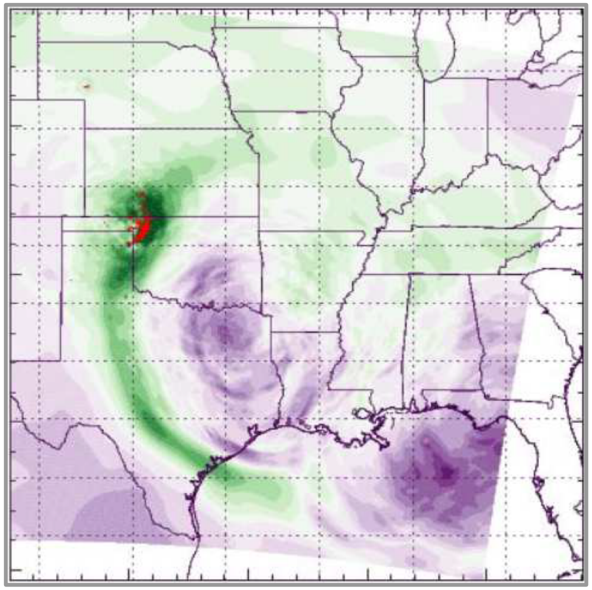
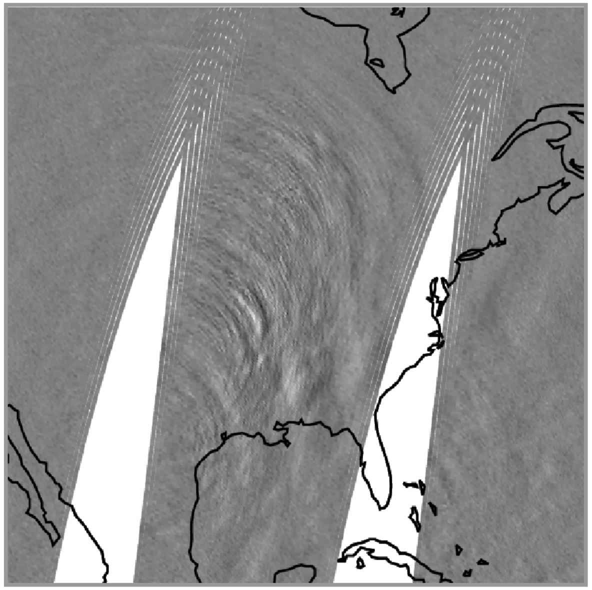
Gravity waves from convection impact weather & climate on many scales

Surface



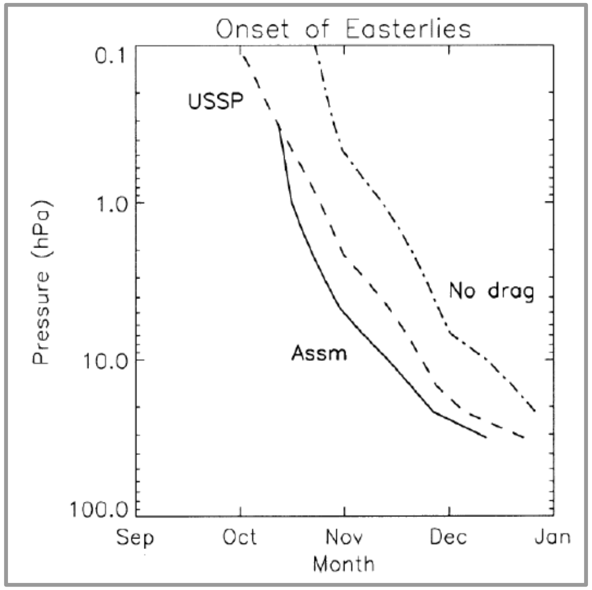
Simulated surface pressure perturbations from idealized model. Convectively-generated GWs interact with active convection (red).

Stratosphere



Convectively-generated GWs in the stratosphere observed by the AIRS satellite.

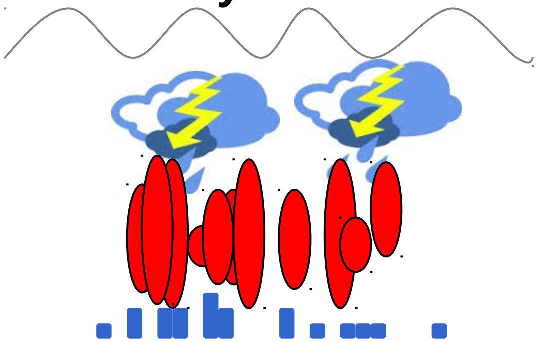
Global circulation



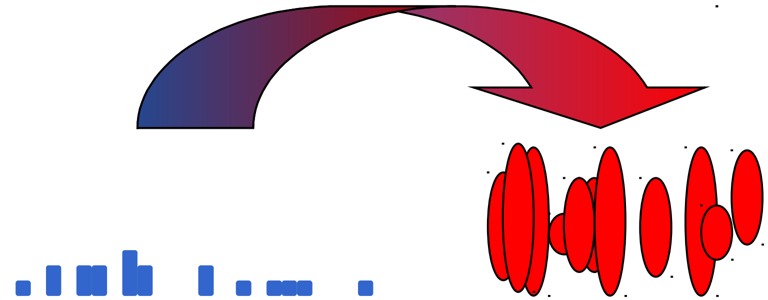
Seasonal descent of the zero zonal mean wind line at 61.25 S in the MetUM. Scaife et al. (2002)

Idealized modeling approach

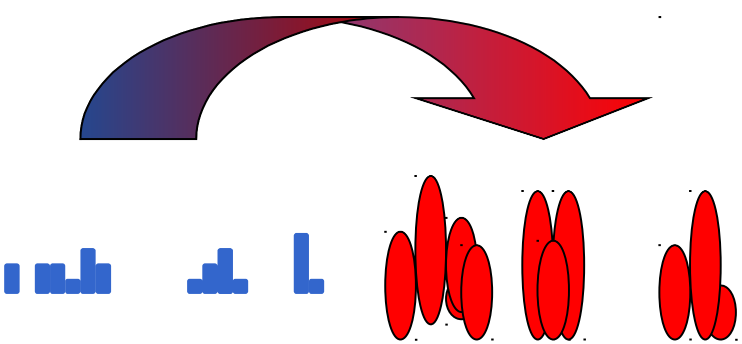
Full-Physics Model



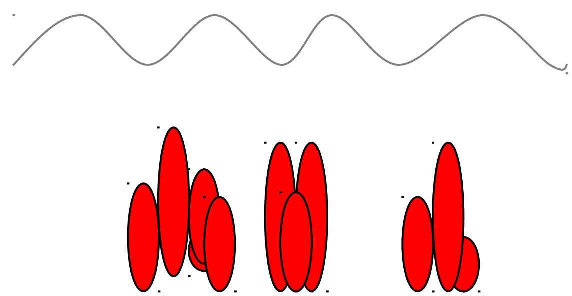
Heating algorithm



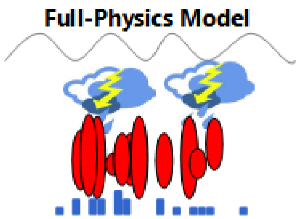
Apply to observed precipitation



Run Idealized Model forced with Q(x,y,z,t)

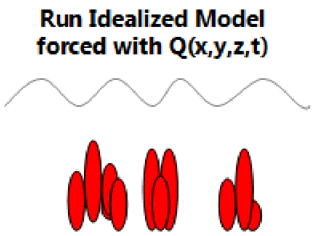


Why develop an idealized model ?



Cloud-resolving model:

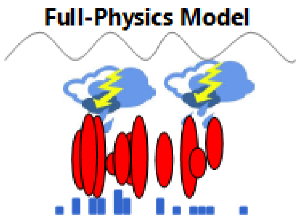
- Convective cells are not in the right place at the right time
- No direct observational validation of local/instantaneous GW amplitudes possible
- These matter: turbulence, mixing, breaking levels



Idealized model:

- Compare to surface GW observations
- Compare to satellite GW observations
- Inform GCM GW drag parameterizations
- Disentangle complex processes

Full-physics model



We need a full-physics model that generates realistic heating and realistic waves!

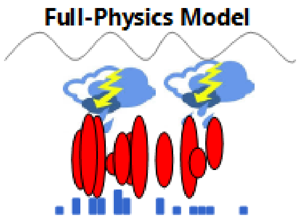
Run	15 km		3 km and 1 km	
	CU	PBL	MP	PBL
MOR I	KF	YSU	MOR	YSU
MOR II	BMJ	MYJ	MOR	MYJ
MOR III	G3	YSU	MOR	YSU
WSM6 I	KF	YSU	WSM6	YSU
WSM6 II	BMJ	MYJ	WSM6	MYJ
WSM6 III	G3	MYJ	WSM6	MYJ
WDM6 I	KF	YSU	WDM6	YSU
WDM6 II	BMJ	MYJ	WDM6	MYJ
WDM6 III	G3	YSU	WDM6	YSU
MY I	KF	YSU	MY	YSU
MY III	G3	YSU	MY	YSU
TOM I	KF	YSU	TOM	YSU
TOM II	BMJ	MYJ	TOM	MYJ
TOM III	G3	MYJ	TOM	MYJ

Potential problem:

Many physics schemes!
Many hydrometeor distributions!

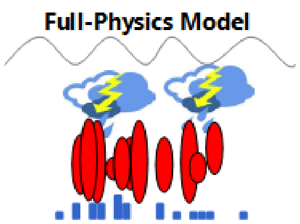
How different will the heating distributions be?
How does this affect the waves?

Full-physics model



Results from ensemble runs:
Microphysics scheme strongly affects hydrometeor distributions
But: The average heating profiles are relatively similar

Full-physics model



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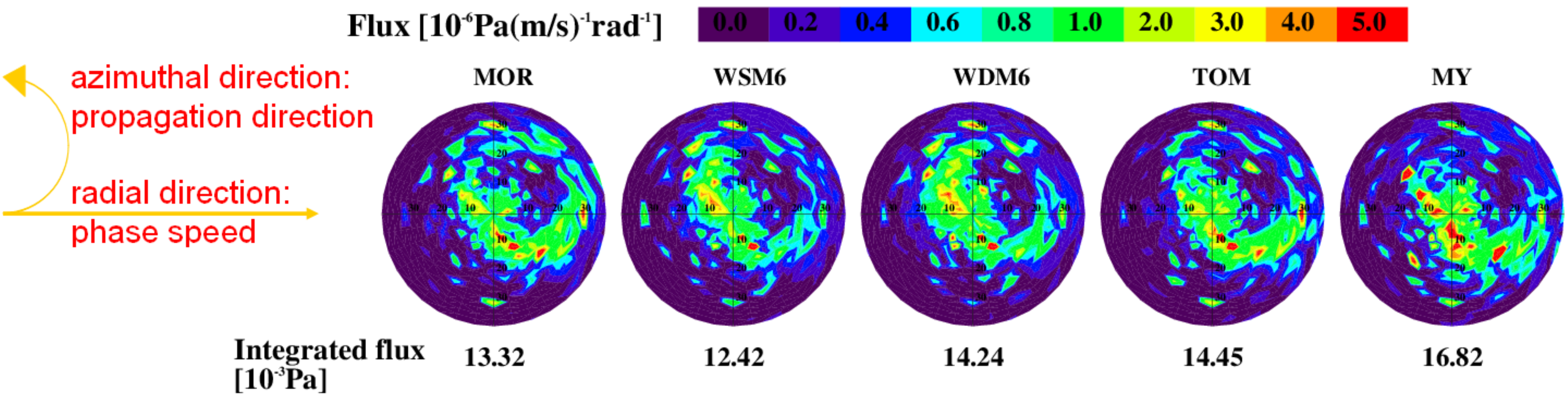
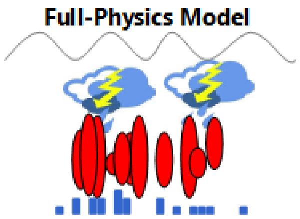
Microphysics scheme strongly affects hydrometeor distributions
<u>But:</u> The average heating profiles are relatively similar

<u>Most importantly:</u>



Full-physics model



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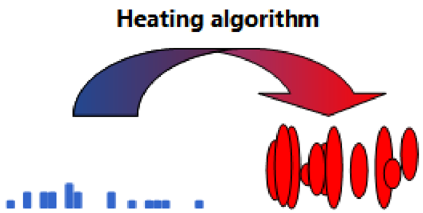
Momentum flux spectra of GWs above simulated storms are relatively insensitive to the choice of microphysics scheme

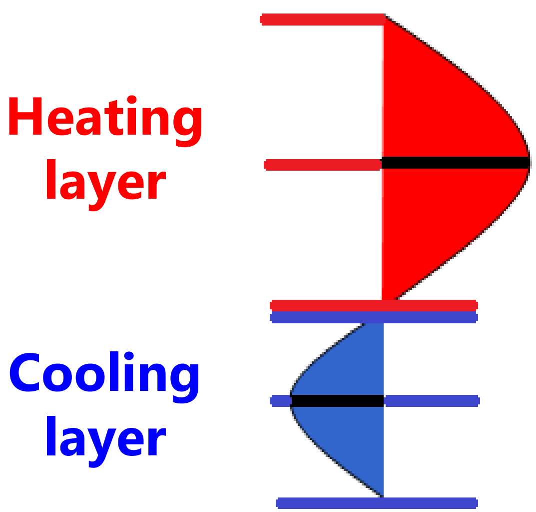
Time-mean, large-area average properties are robust

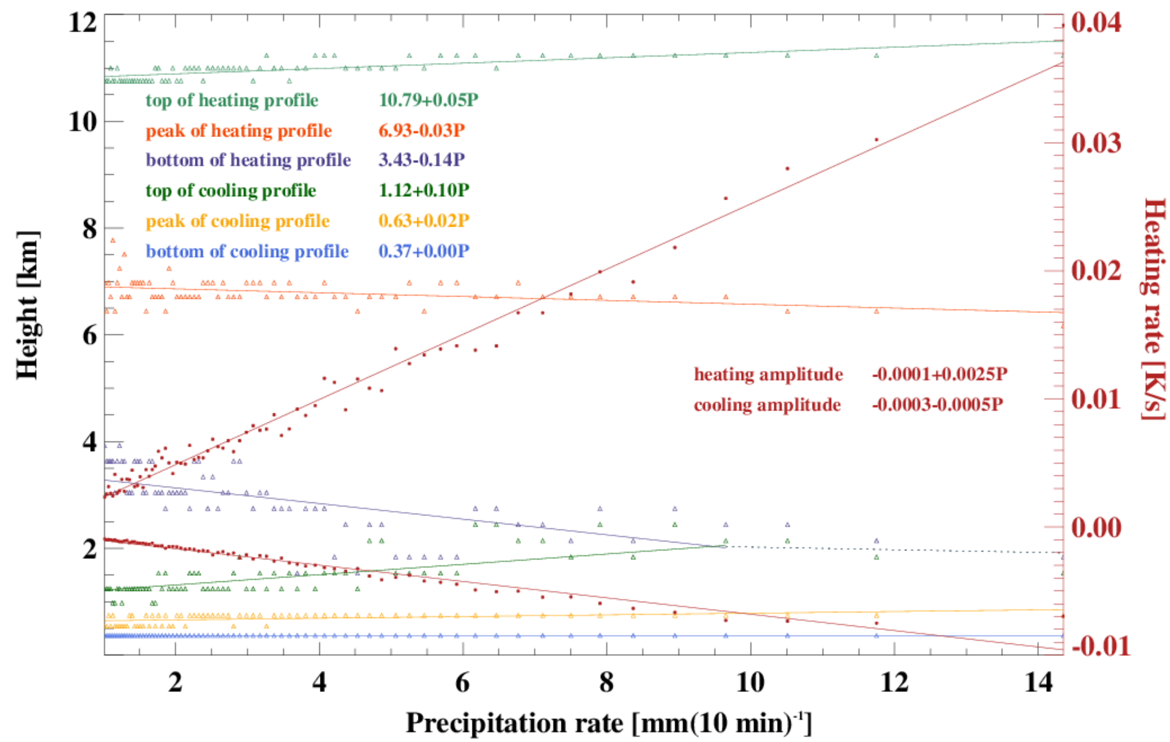
But are the wave amplitudes realistic?

Heating algorithm

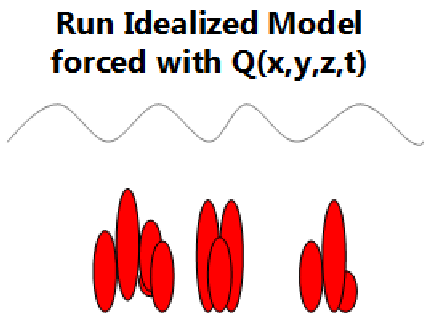


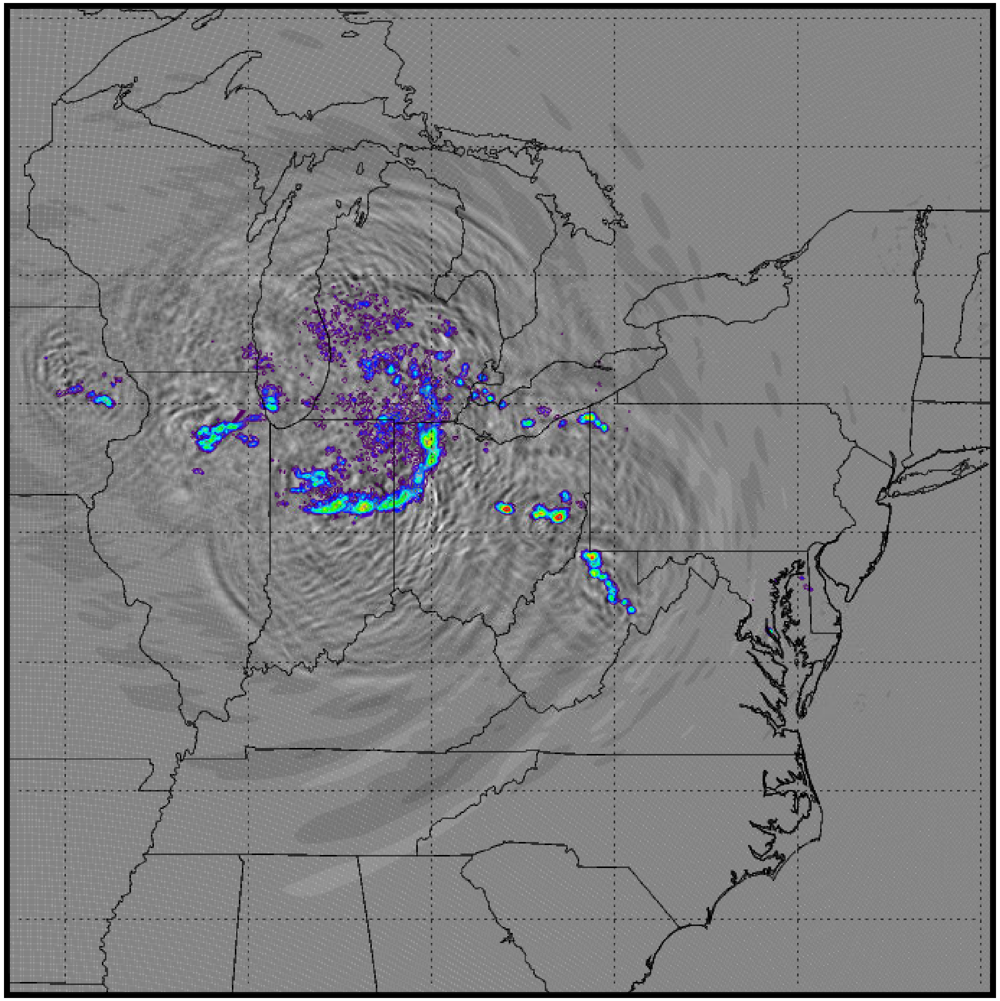
- Converts 4 km x 4 km 10 min precip. rates (x,y,t) to vertical profile of Q(x,y,t,**z**)
- Derived from full-physics simulations
- Implicitly includes: advection, evaporation and ice-phase processes





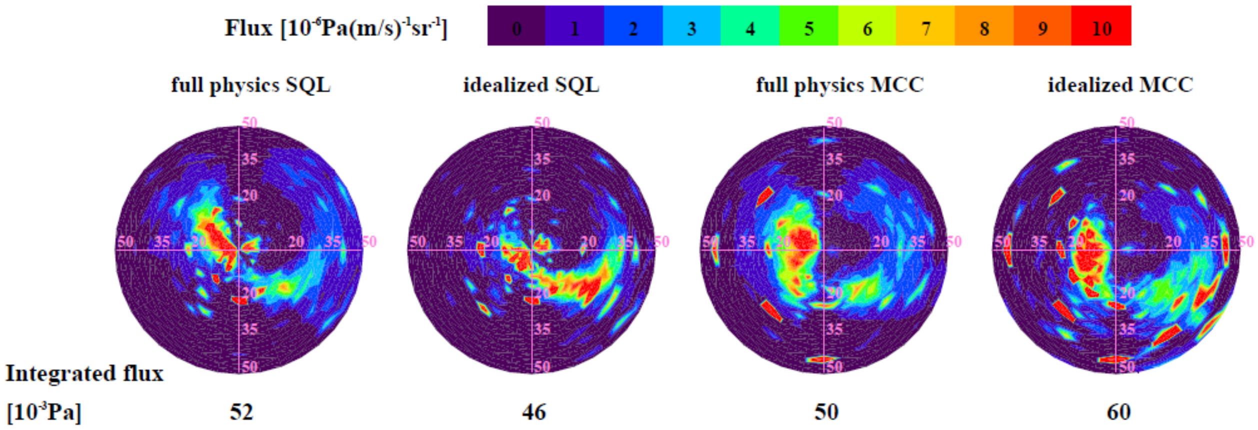
Idealized model forced with NEXRAD obs.





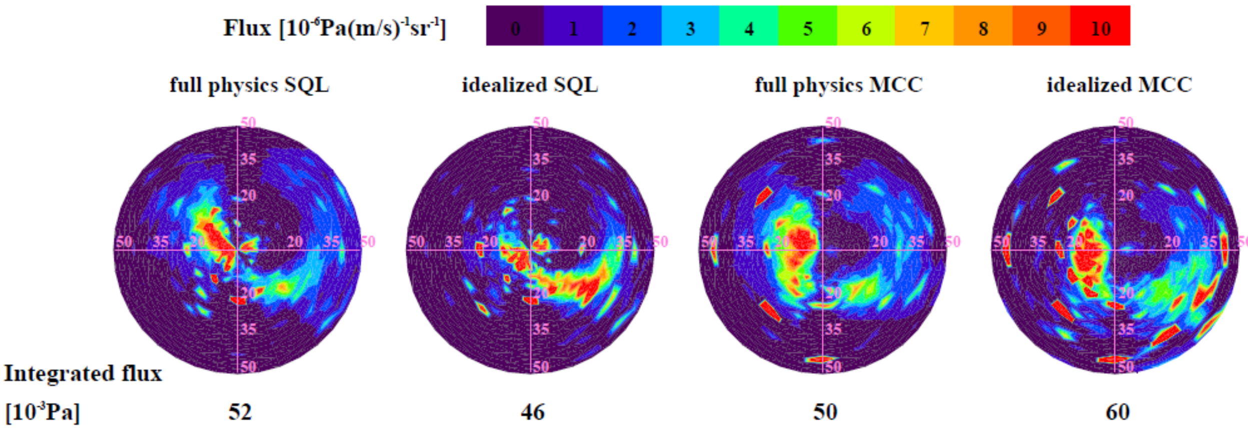
Idealized model snapshot
Radar precipitation (colors)
and
wave vertical velocities
(shades of gray)

Idealized model: Validation



Idealized model reproduces spectra of full-phys. model...

Idealized model: Validation



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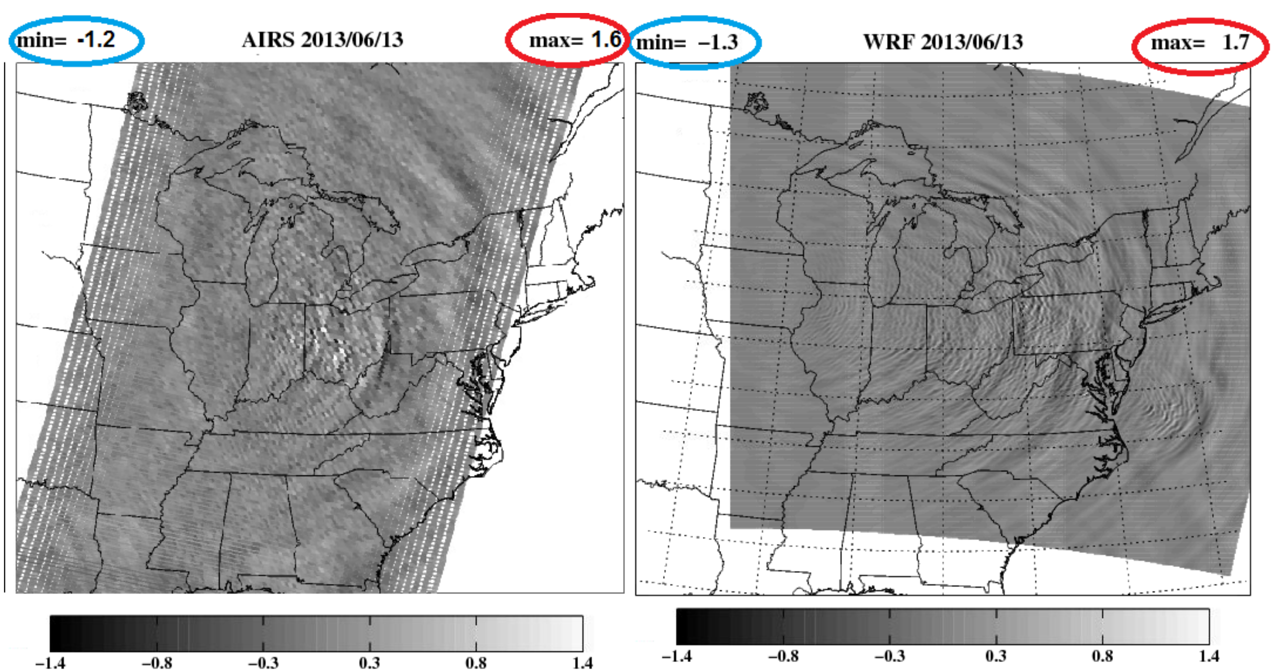
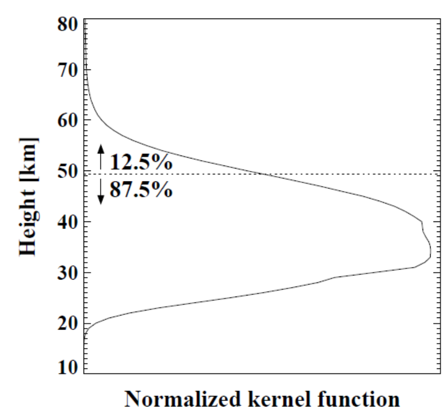


…and satellite observations with correct amplitudes!



Impacts on the stratosphere

Can this model inform GWD parameterizations for GCMs?

- Key parameters: local/instantaneous amplitudes
- Tied to strength and depth of latent heating
- Even in most advanced parameterizations these are unresolved

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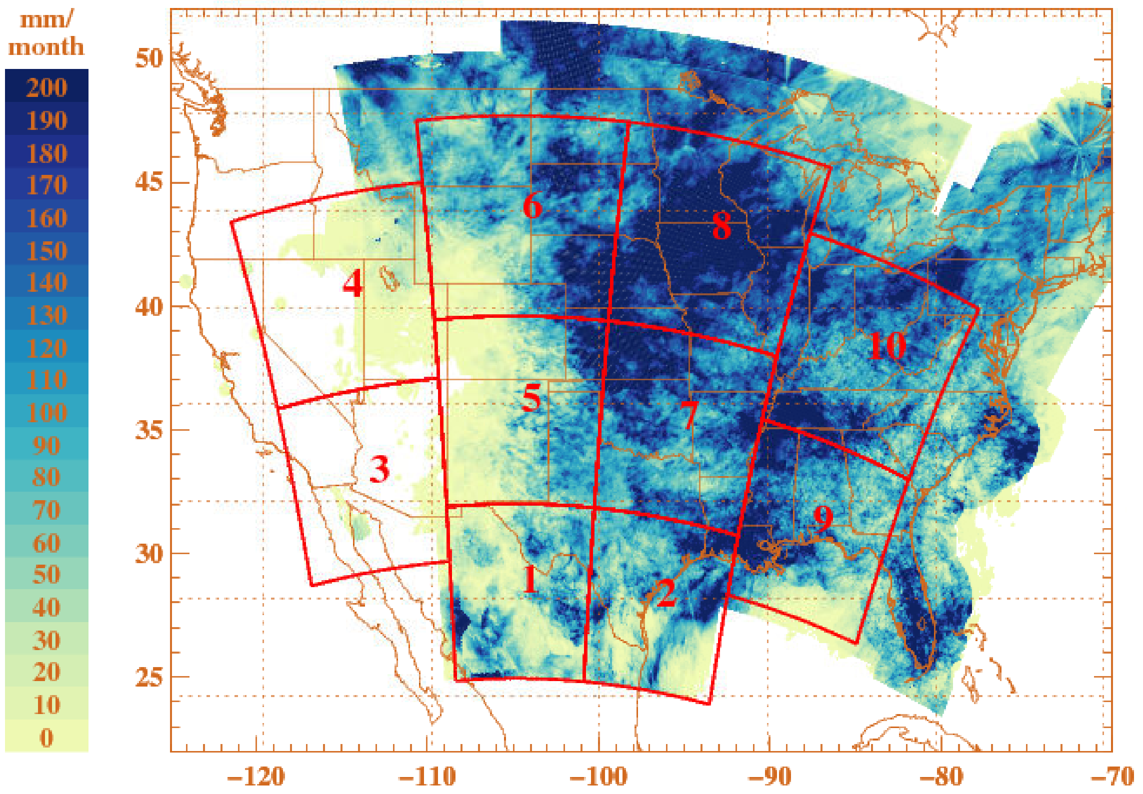
Our simulations:

June 2014: Continental US
4 km resolution; 65 km top

Based on observed precipitation

Split up into 10 domains &
24 h runs with 1d-initialization



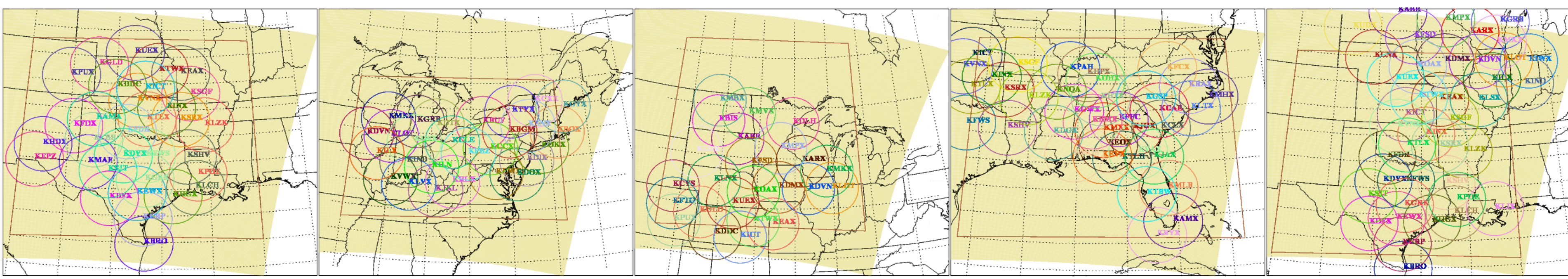
Towards continental scale simulations

We only have *hourly* 4 km x 4 km data available (NCEP Stage IV)

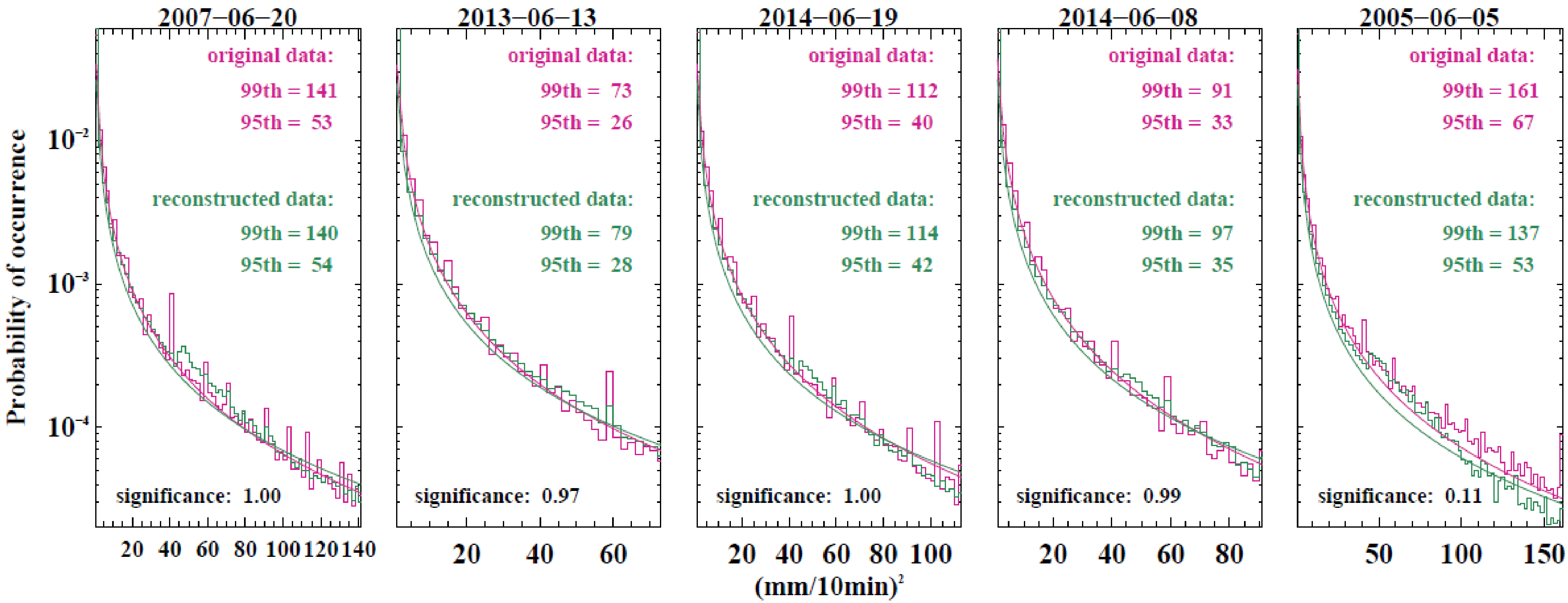
$$m = P10/P60, \text{ where } 0 \le P10 \le P60 \text{ and } 0 \le m \le 1$$

$$P(m|P60) = \frac{1}{m\sigma\sqrt{2\pi}} e^{\frac{-(\ln(m)-\mu)^2}{2\sigma^2}}$$

category:	$0 < P60 < 10$	$10 \le P60 < 20$	$20 \le P60 < 30$	$30 \le P60 < 40$
ν	0.58	0.33	0.23	0.15
μ	−1.29	−1.76	−1.86	−1.90
σ	0.97	0.98	0.96	0.88

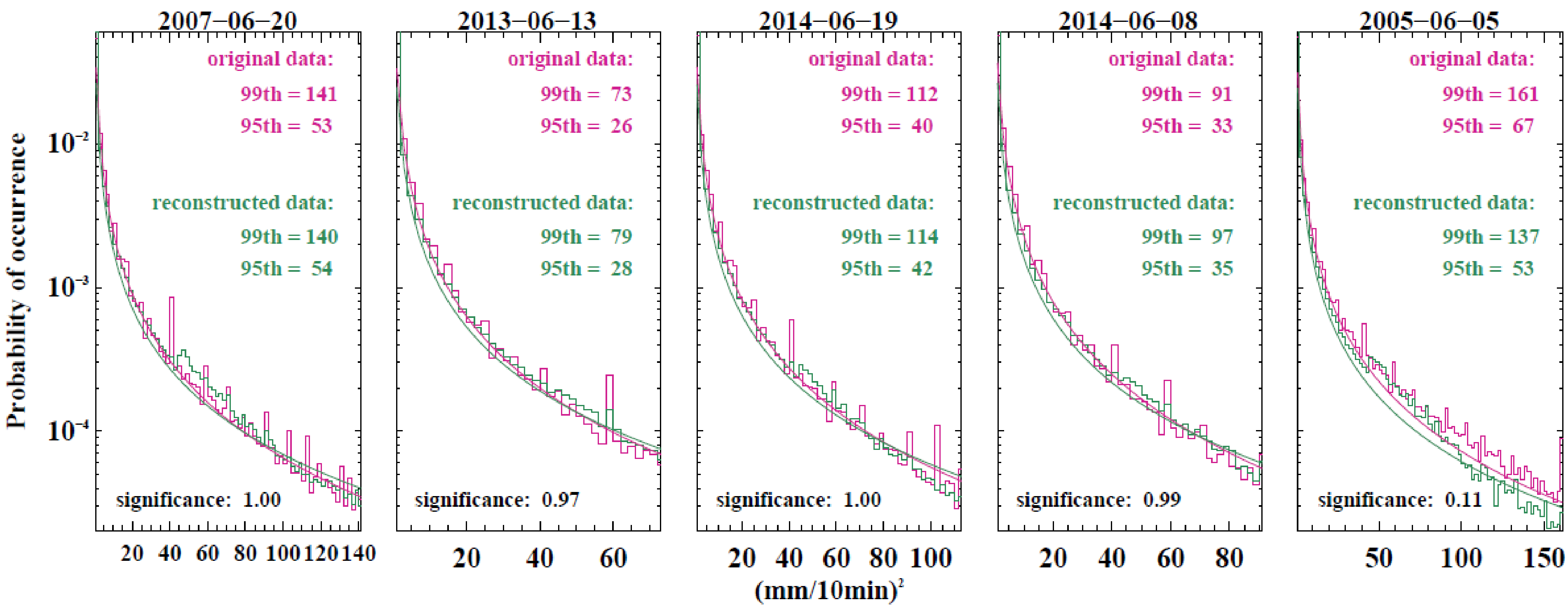


Precipitation downscaling: Validation



- ✓ Precipitation algorithm reproduces 10 min 4 km x 4 km PDFs from hourly values

Precipitation downscaling: Validation

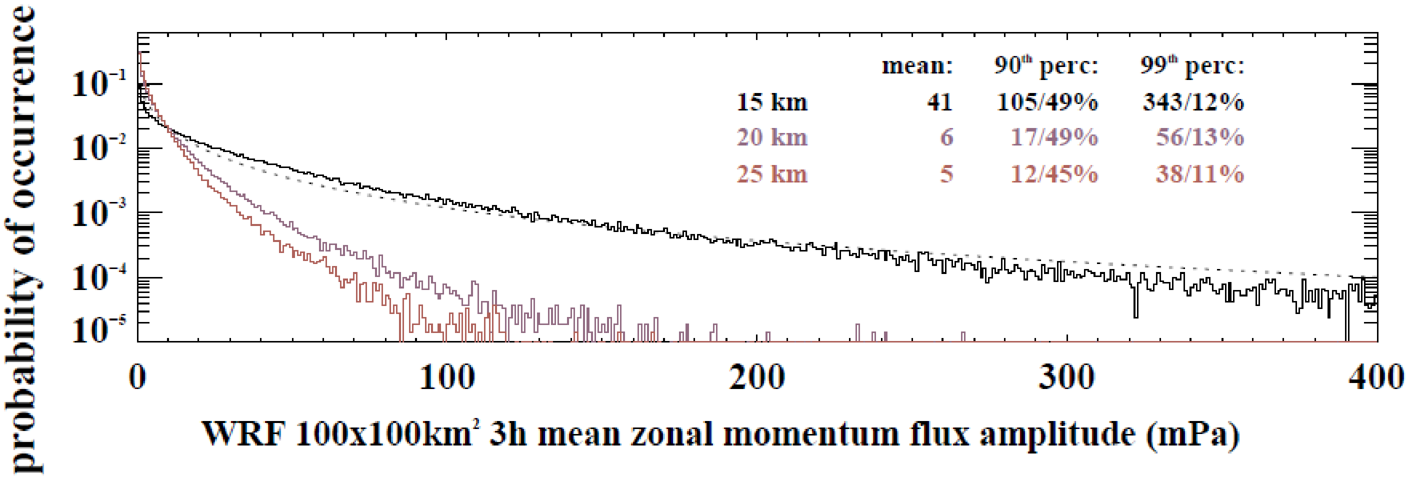


✓ Precipitation algorithm reproduces 10 min 4 km x 4 km PDFs from hourly values

Is this good enough? Will the sub-hourly distribution change the GW spectra?

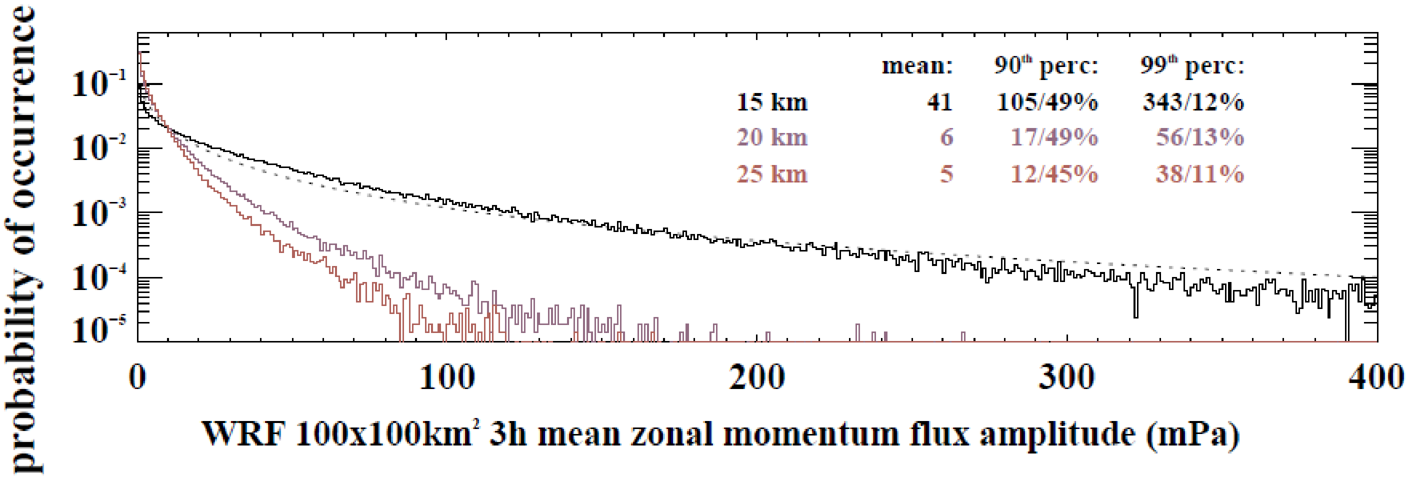
✓ We tested this in simulations

Lognormality



Continental simulation, USA

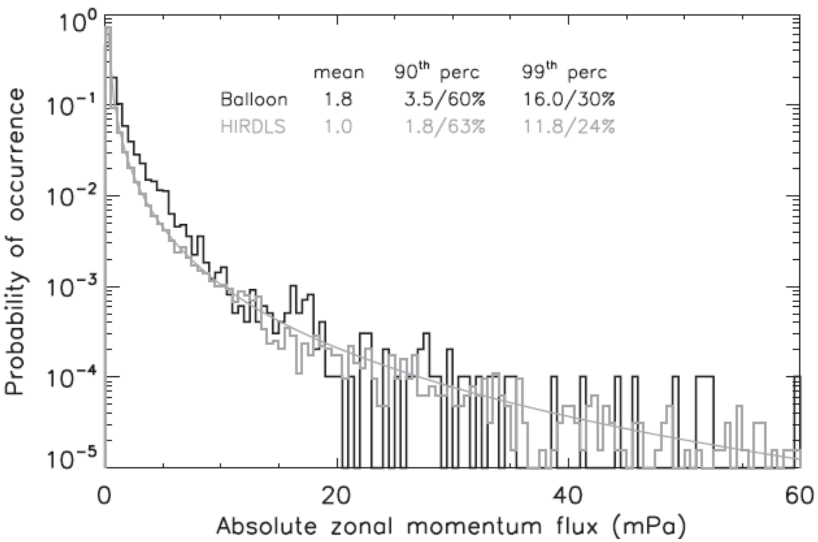
Lognormality



Continental simulation, USA

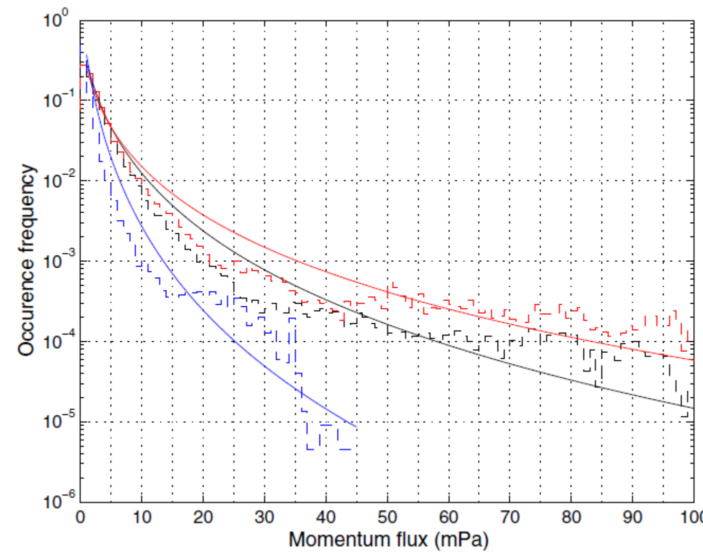
PreConcordiasi, Tropics

Jewtoukoff et al., 2013

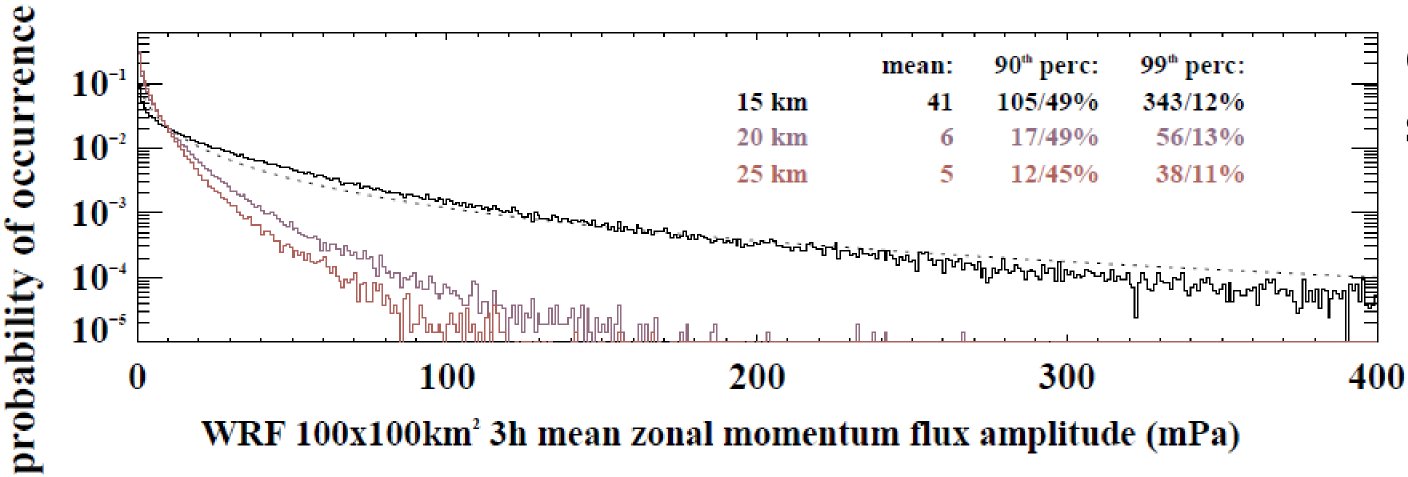


Vorcore balloon & HIRDLS, 50-65°S

Hertzog et al., 2012



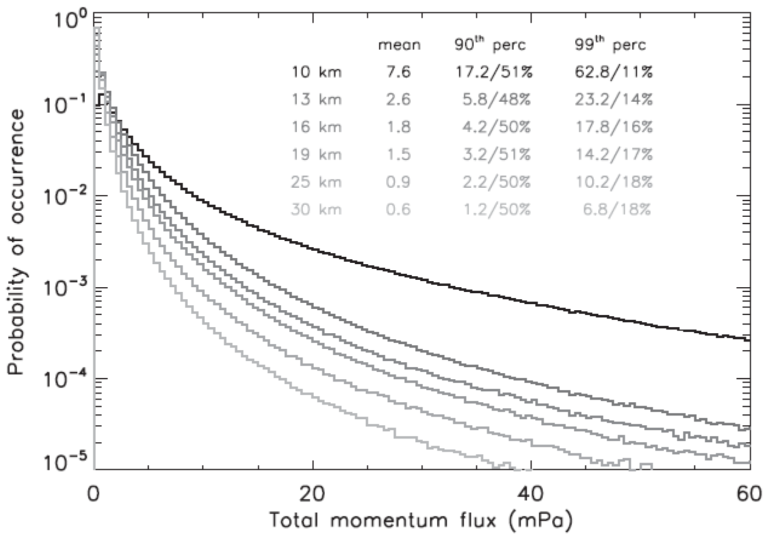
Self-similarity



Continental simulation, USA

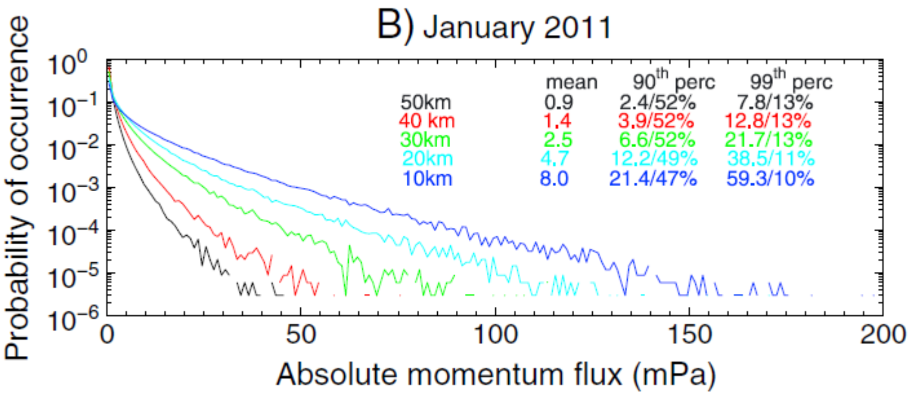
WRF simulation, Antarctica

Hertzog et al., 2012

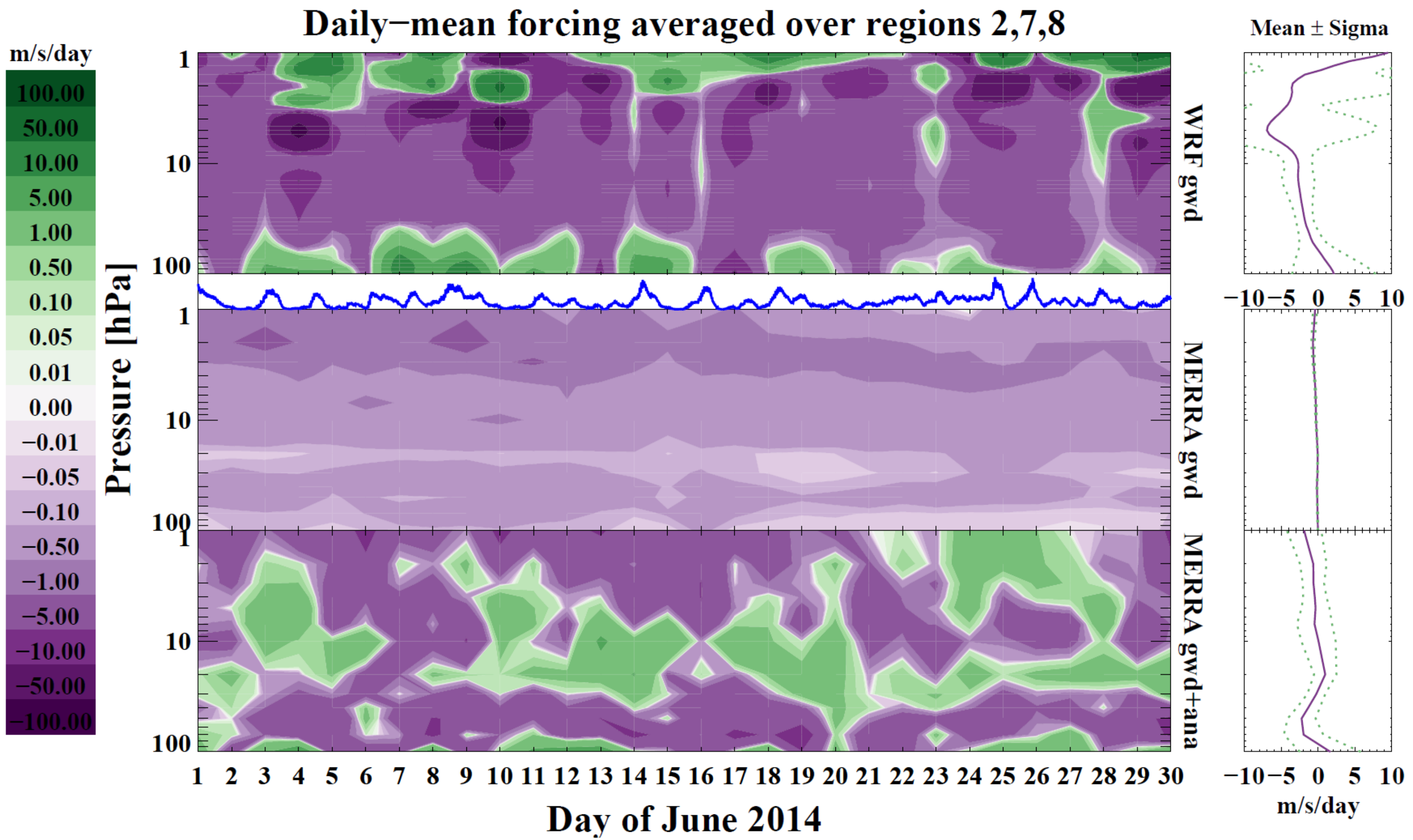


Stochastic parameterization

De la Camara et al., 2014



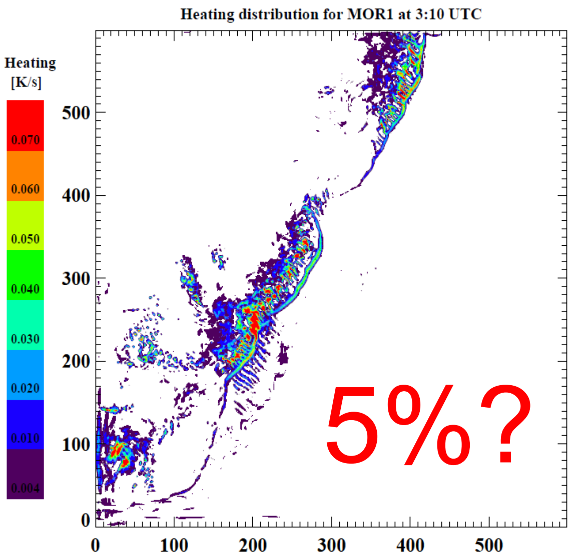
GWD in WRF versus MERRA



CAM source parameterization

Beres et al., 2005 parameterization

- Tied to model convective latent heating
- Magnitude of heating is uncertain
- Assumes convective fraction of 5%



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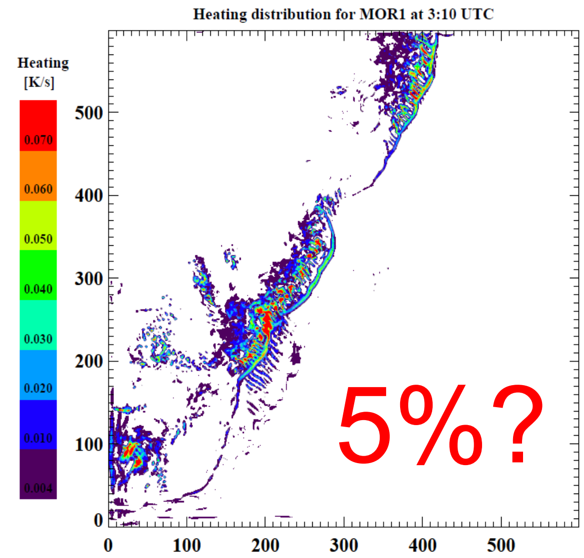
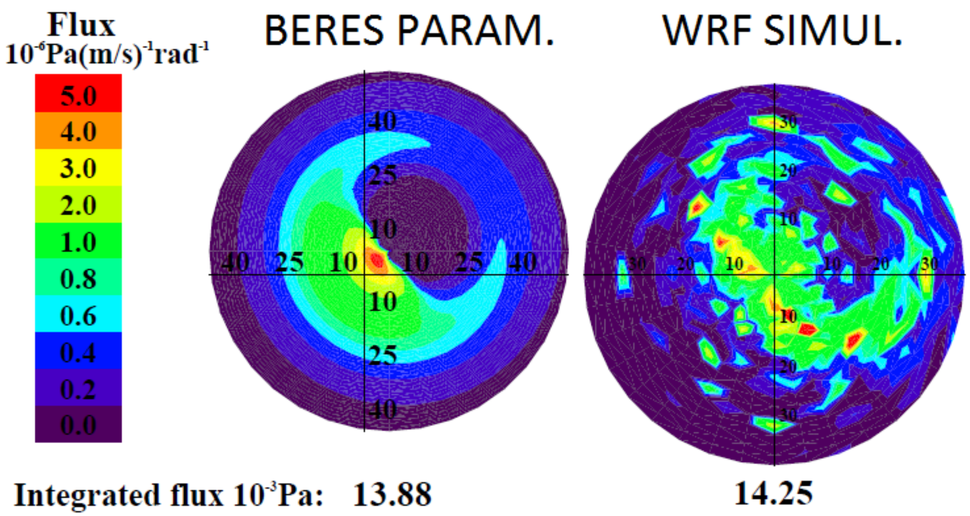
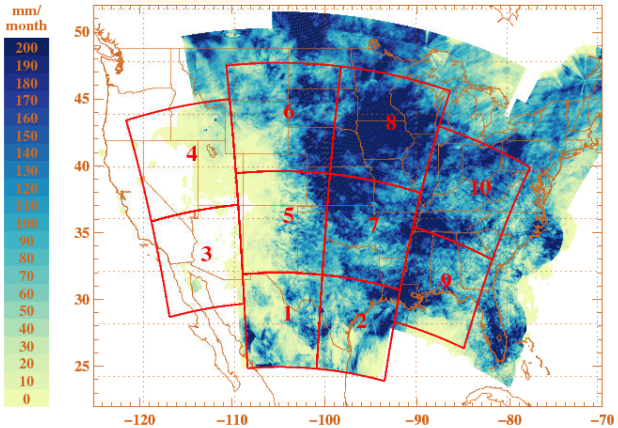




Parameterization vs WRF

- Input to parameterization: parameters of simulated heating
- Area-mean time-average: good performance

GWD in WRF, CAM and MERRA



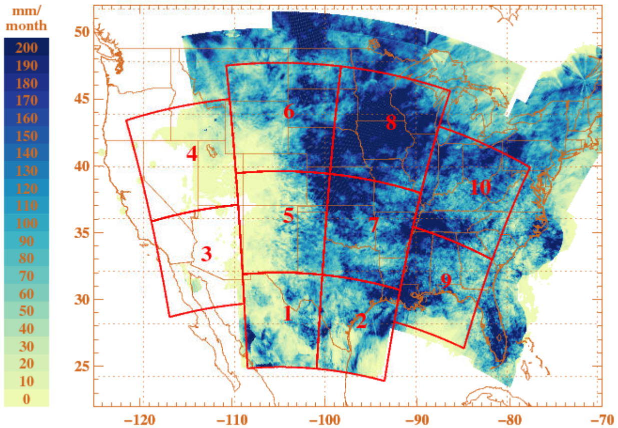
This table shows:

For the area covered by WRF domains:

The simulated wave drag x 0.16 in units of m/s/day averaged over equally-spaced pressure levels

pressure range:	100 – 10 hPa	10 – 1 hPa	1 – 0.4 hPa
WRF gwd	−0.072	−0.156	0.639
CAM conv. gwd	−0.003	−0.014	0.044
CAM oro. gwd	−0.009	< 0.001	0.001
CAM fro. gwd	−0.008	−0.035	−0.030
CAM tot. gwd	−0.019	−0.048	0.015
MER gwd	−0.009	−0.029	0.025
MER gwd+ana	−0.052	−0.037	−0.183

GWD in WRF, CAM and MERRA



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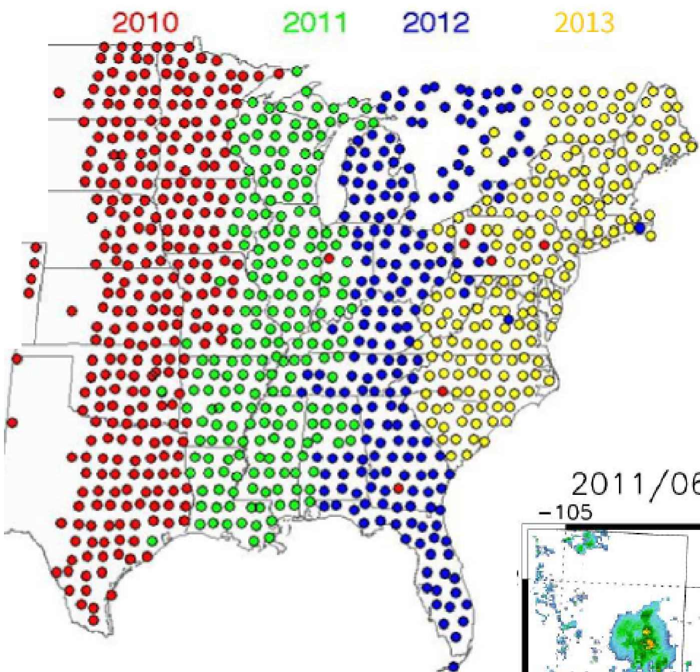
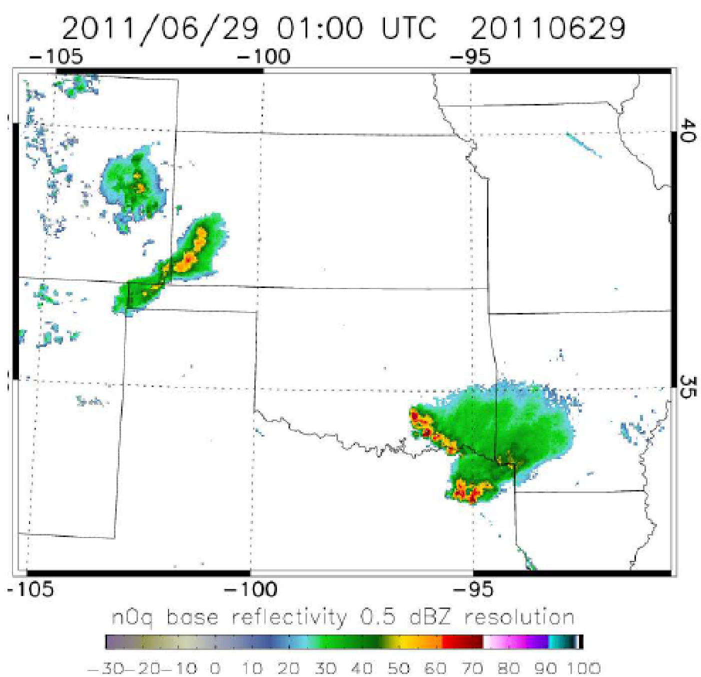
Things to note:
- WRF has larger forces at 100-10 hPa than MERRA and CAM
- Conv.-generated GWs can have large amplitudes → break low
- Could be improved: Use precip. downscaling instead of 5% assumption

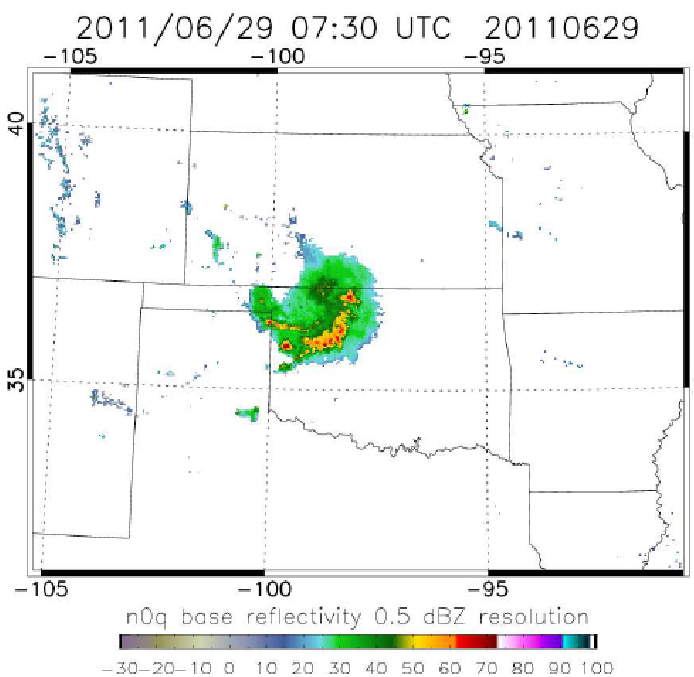
Back to the earth



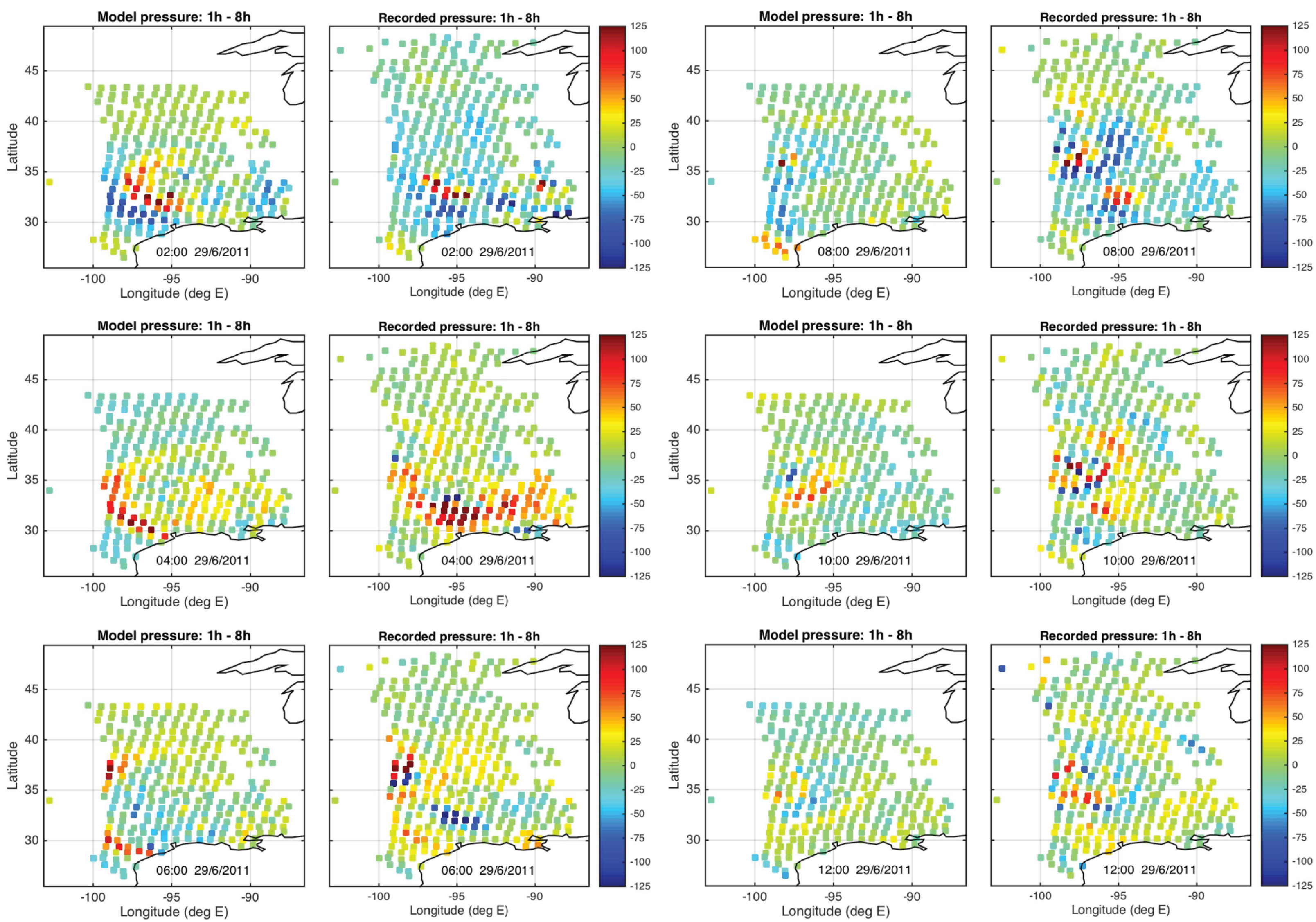
Can we identify the sources of waves observed by the US Transportable Array?

Case study using the idealized model: Compare simulated waves in the troposphere to surface observations





Model versus surface observations



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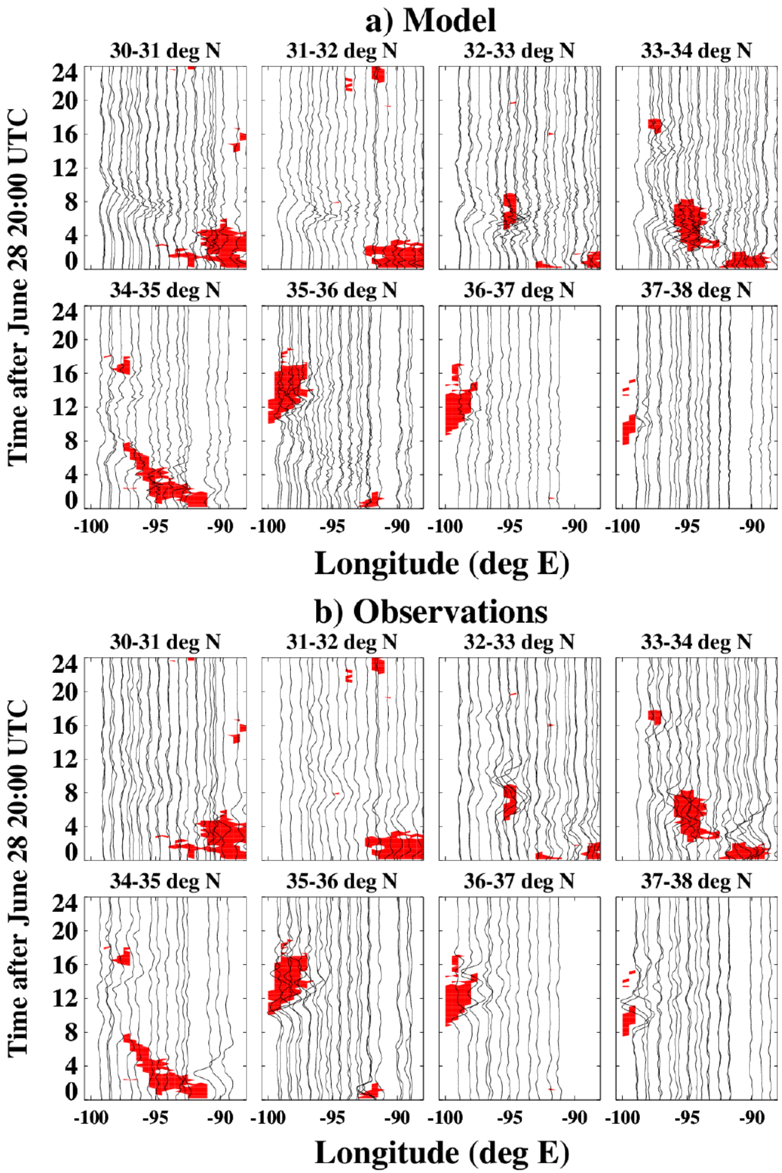

- Times series of model predictions and recorded data at locations of stations in the Transportable Array
- Precipitation is shown in red
- 1 deg longitude = 300 Pa

Summary

- New modeling approach: Idealized WRF model forced with heating/cooling
- Observationally validated with satellite and surface measurements

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- Momentum flux spectra are characterized by universal lognormal distributions with long tails
- Neither constant- nor variable-source parameterizations include enough high-amplitude waves
- Strong and highly intermittent forces at 100 hPa-60 hPa are not correctly represented in GCMs
- This can be fixed: Combine Beres parameterization with a stochastic approach

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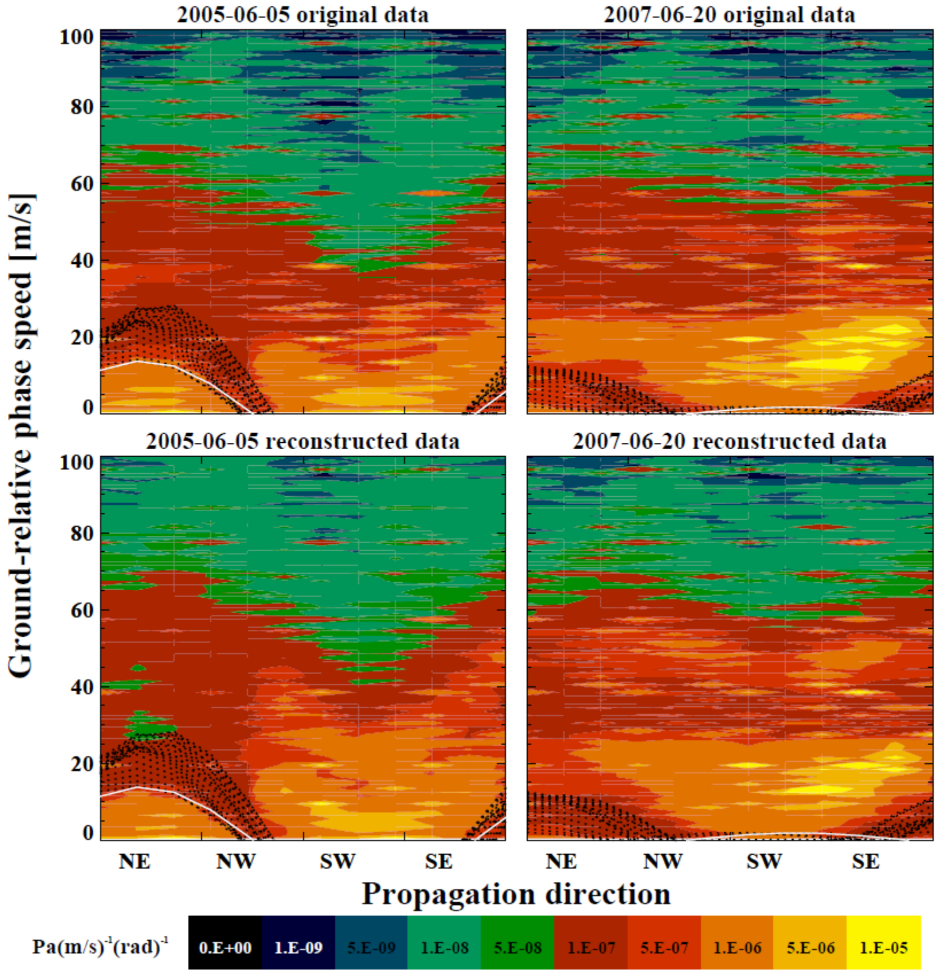
- This model can perform well close to the surface
- More useful applications: wave-convection interactions, turbulence, ?

Precipitation downscaling: Validation

Is this good enough? Will the sub-hourly distribution change the GW spectra?



model based on original 10 min data

model based on reconstructed data

Precipitation downscaling: Validation

How about local amplitudes?