Filling the resolution gap between global models and applications: dynamical and/or stochastic downscaling

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Overview

- Atmospheric fields display complex variability over vast range of scales (space & time)

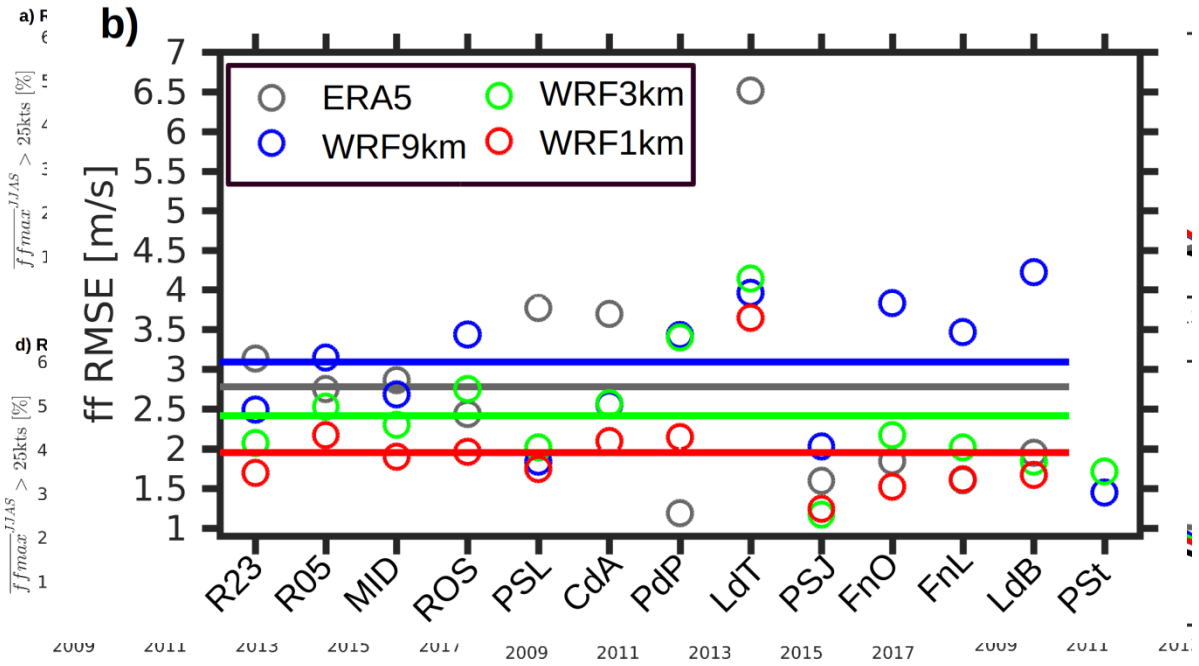
- Global models have insufficient resolution for many weather & climate applications
- Does increasing model resolution solve all problems (panacea) or adds spurious information (illusion)?
- How accurate are high-resolution simulation in simulating small-scale variability?
- How much does dynamical downscaling depends on large-scale forcing?
- How can we optimize predictions with stochastic methods?

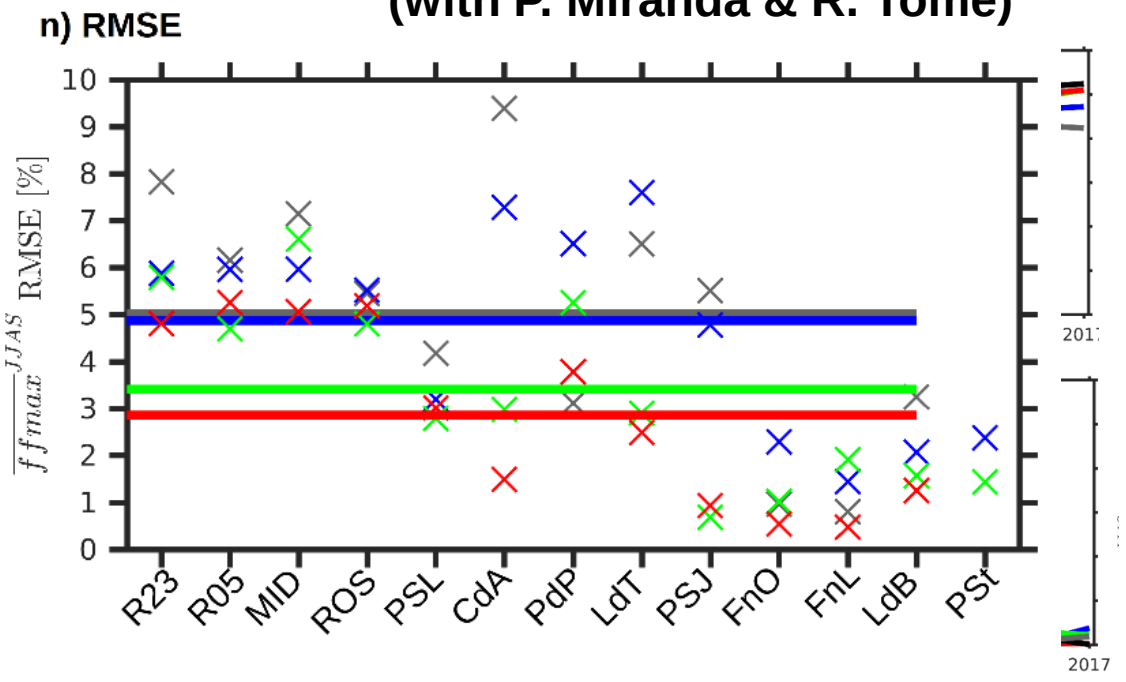
Dynamical Downscaling in Madeira Island

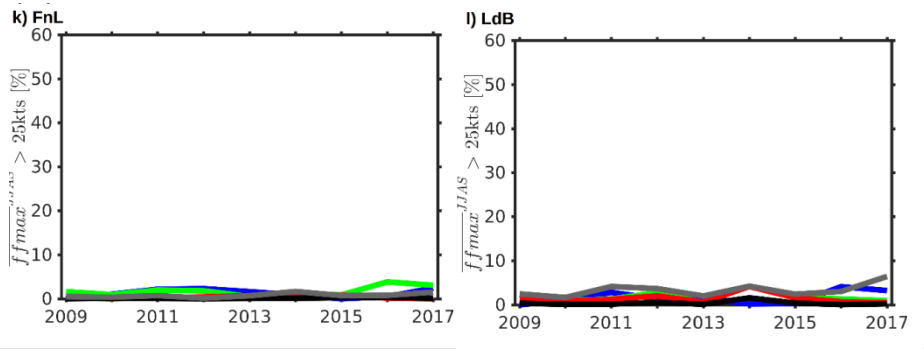
MADEIRA ISLAND WIND (2009-2017): ERA-5 (GLOBAL, 0.25º) → WRF (REGIONAL)

(with P. Miranda & R. Tomé)

PROBABILITY GUST>25kt in JJAS





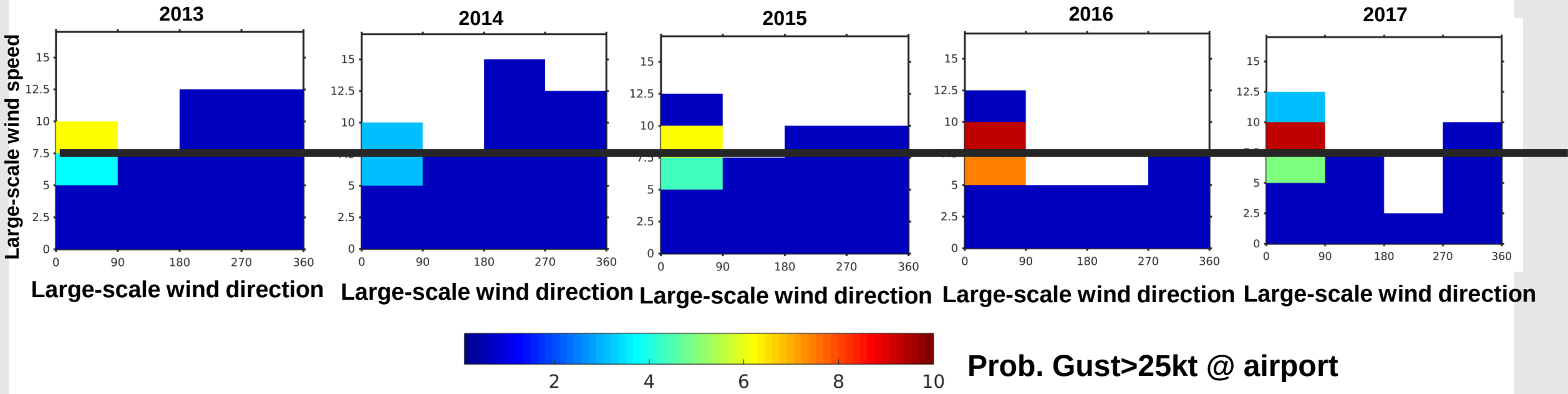


Obs
ERA-5
WRF9km
WRF3km
WRF9km

ERA-5 has relevant information
9km is insufficient
3km & 1km have significant added value
…and can explain the observed behavior

Local-to-large-scale links

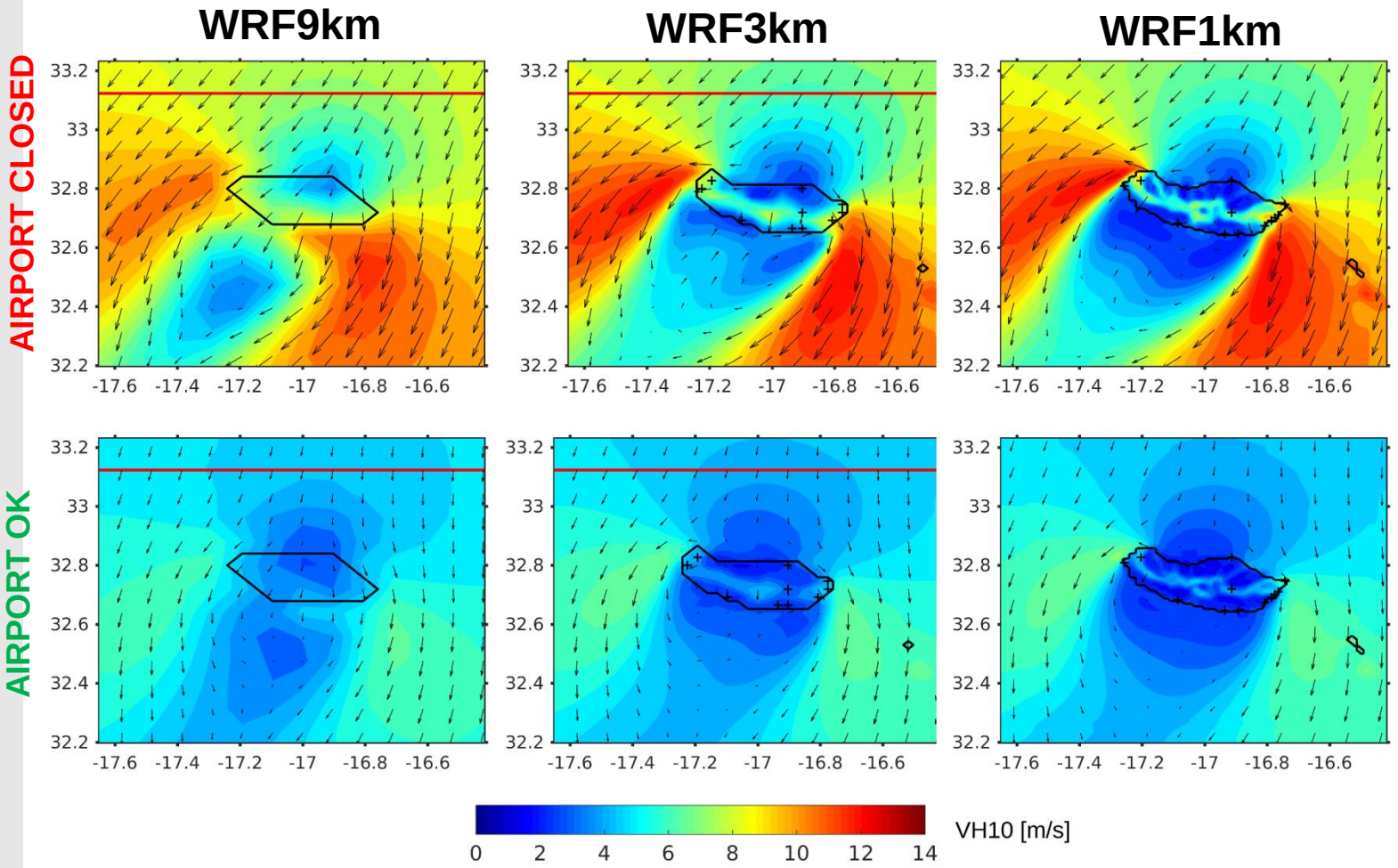
PROBABILITY OF JJAS GUST>25kt CONDITIONAL ON LARGE-SCALE FLOW



- Local changes to gust frequency are tightly linked to changes in large-scale flow;
- Increased freq. of strong northeasterly wind => increased freq. of airport closed;
- Information is on large-scale (ERA-5)
- But internal variability or trend? Study requires long high-resolution simulation…
- … accurate projections requires high-resolution ensemble…

Dynamical Downscaling in Madeira Island

LARGE-TO-SMALL SCALE TRANSFER FUNCTION:



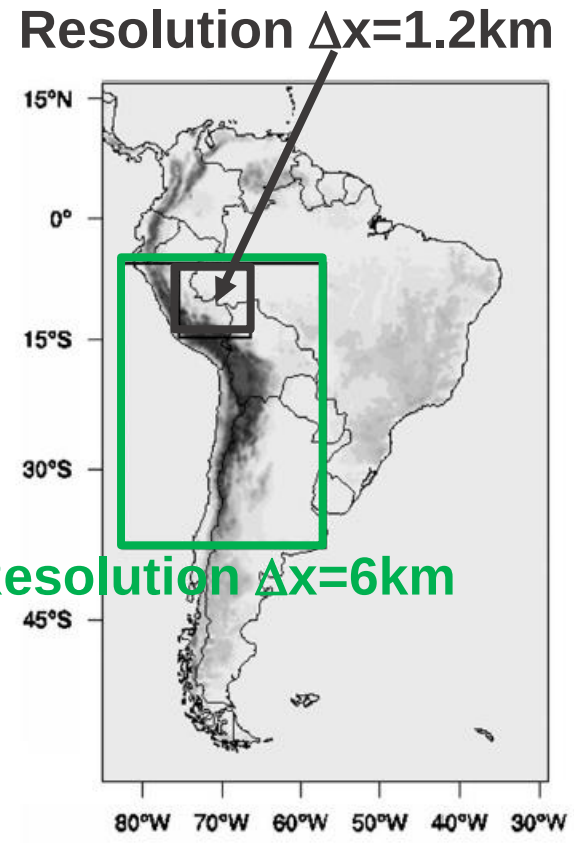
ECMWF (Det.+Ens) large-scale

Large-to-small scale transfer:
- **Dynamical downscaling**
- **Stochastic dowscaling**
- **Combine to get EPS**

SST interaction (J. Alves)

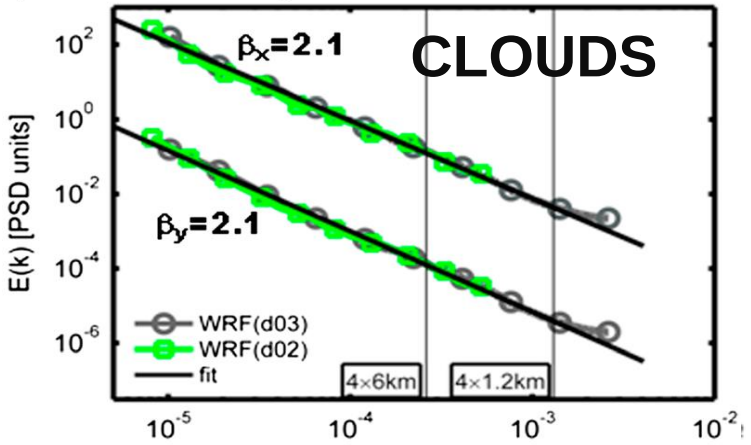
Vertical structure of turbulence (OBSERVATIONS!!!!!)

The Grid vs Effective Resolution Increases



Nogueira & Barros (2014, JGR Atmos.)

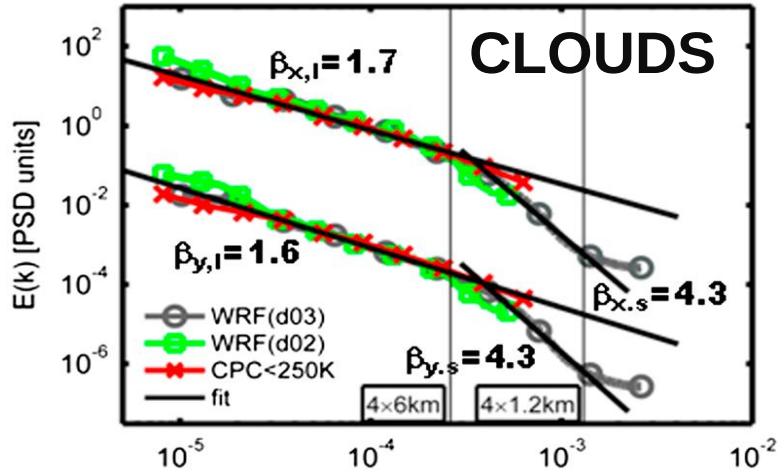
STRATIFORM CASE



Effective Res. < 2Δx

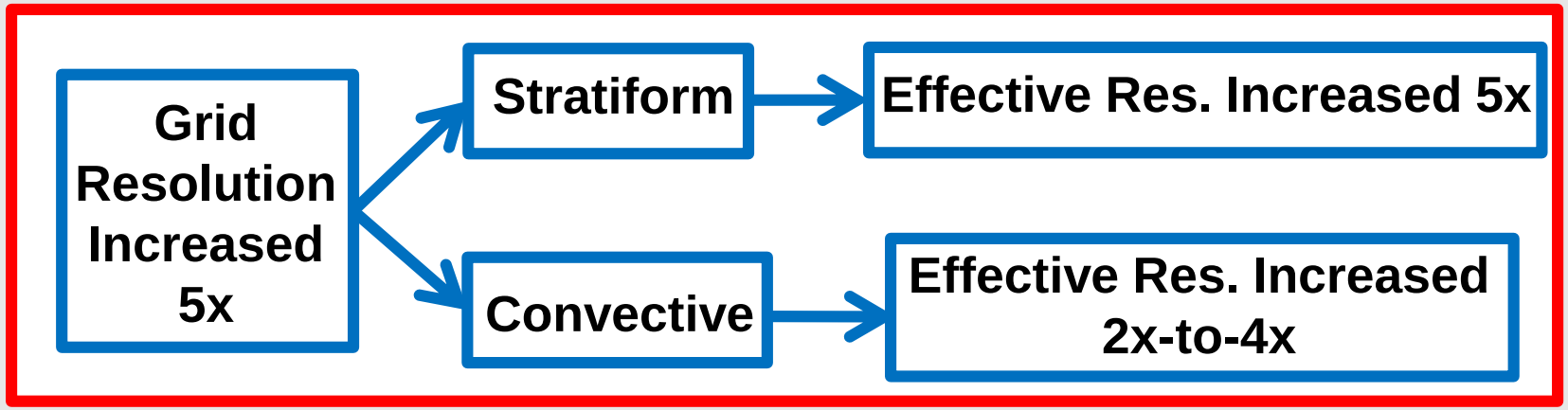
Effective Res. ≈ 2Δx

CONVECTIVE CASES



Effective Res. ≈ 4-5Δx

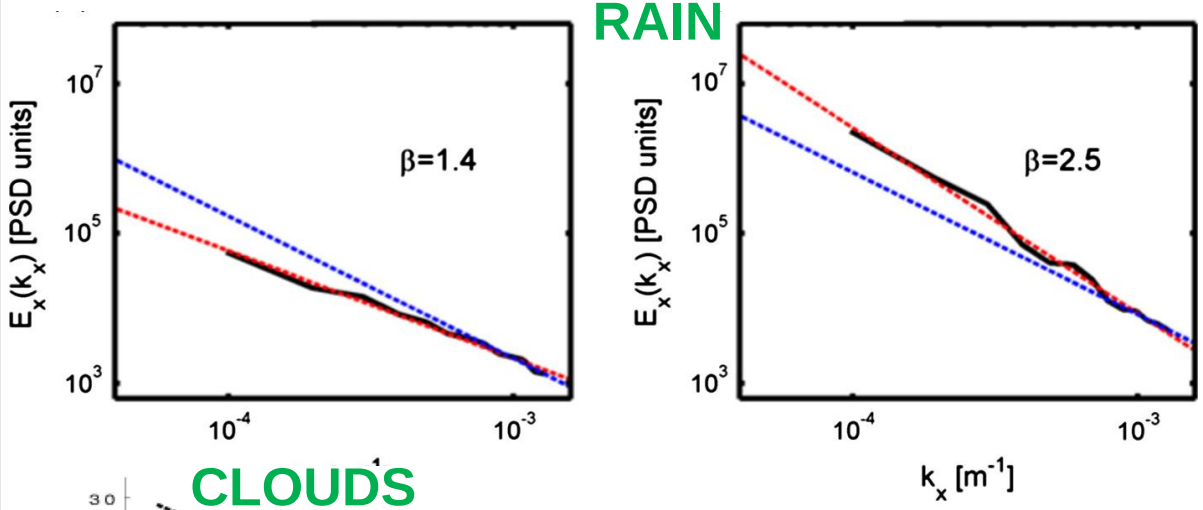
Effective Res. ≈ 6-12Δx



Stochastic Fractal Symmetries Across Scales

SCALE-INVARIANT SYMMETRIES ARE UBIQUITOUS IN THE ATMOSPHERE

RAIN



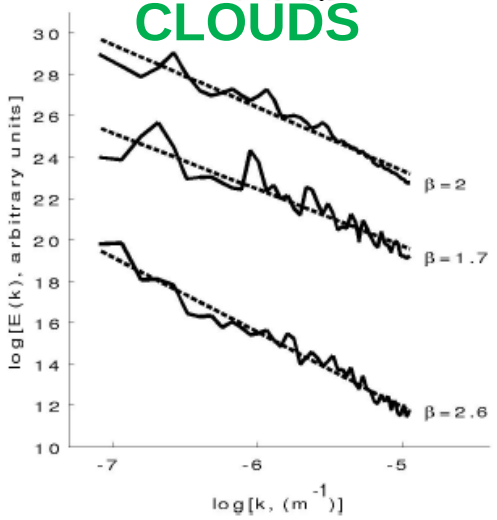
Scale-invariance in wind, rain, clouds, etc.

$$\Delta f(l) = \varphi_1^{\eta} l^{H}.$$

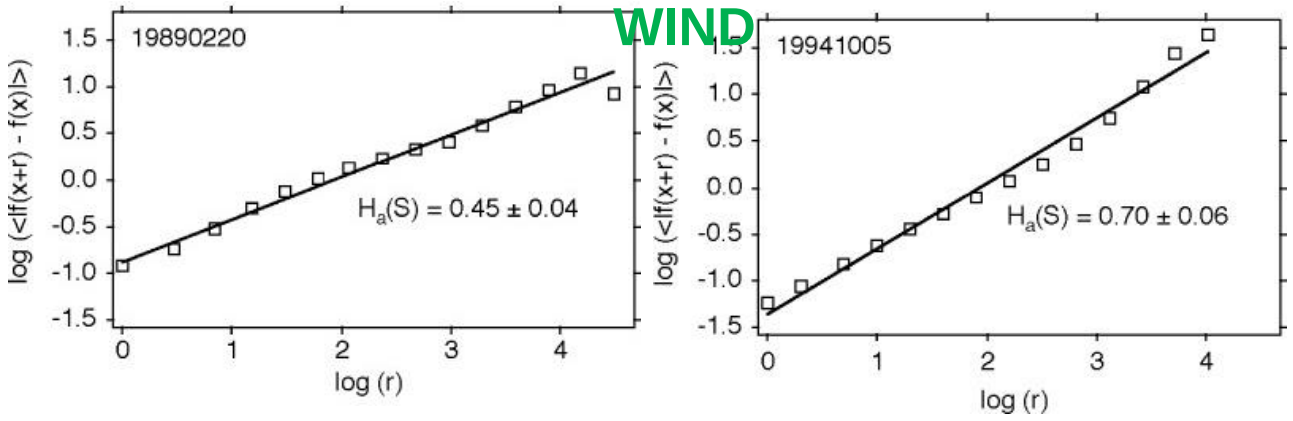
The scaling coefficients are transient…
Namely convectve/stratiform transition

Nogueira & Barros (2015, J. Hydrology)
Nogueira (2017a, JGR Atmos)
Nogueira (2017b, PlOS One)

CLOUDS



WIND



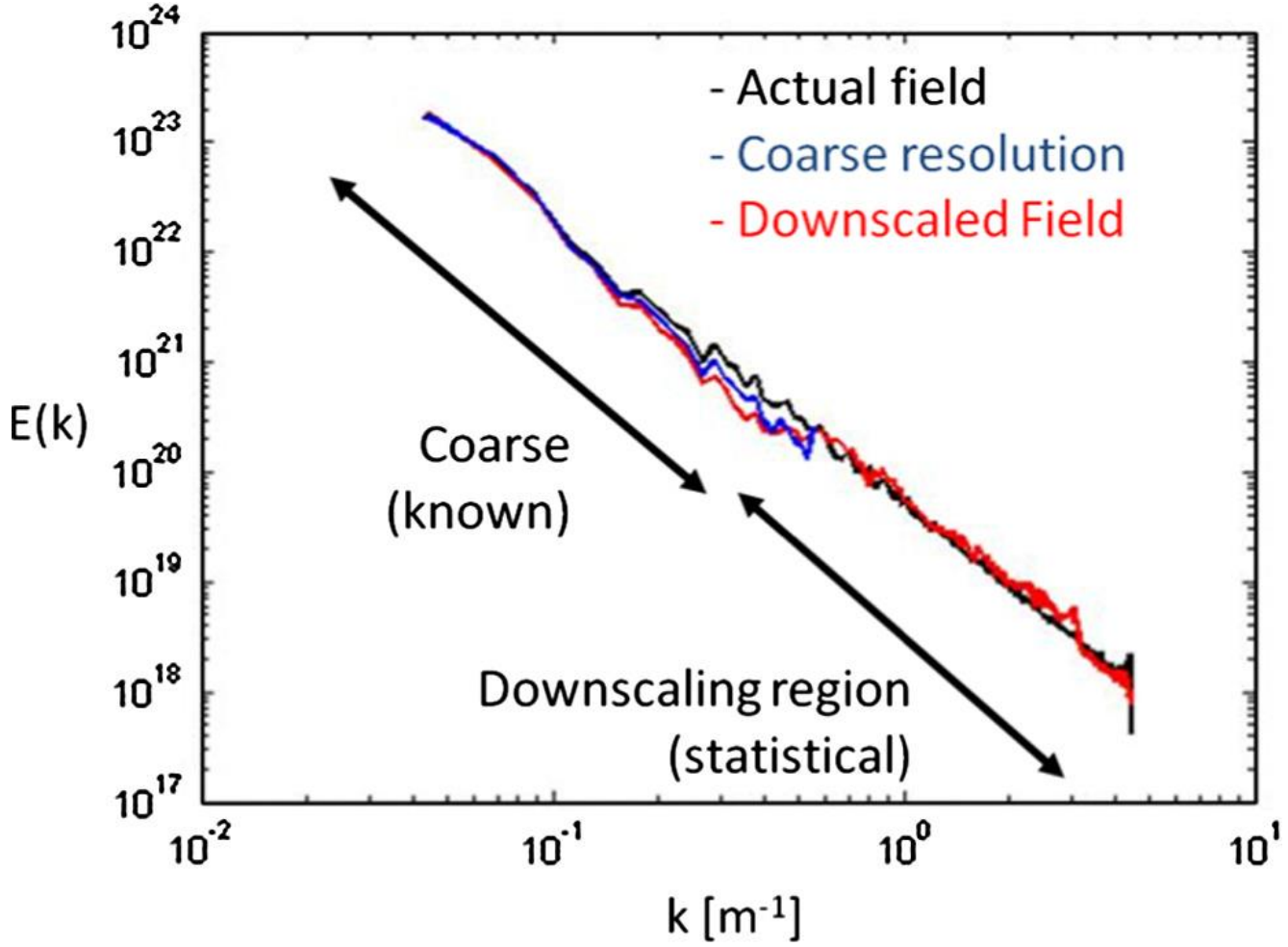
Related to information introduced at different scales (Nogueira, 2017b):

$$H(X) = -\sum_{x_i \in \theta} p(x_i) \log p(x_i)$$

Stochastic Fractal Downscaling

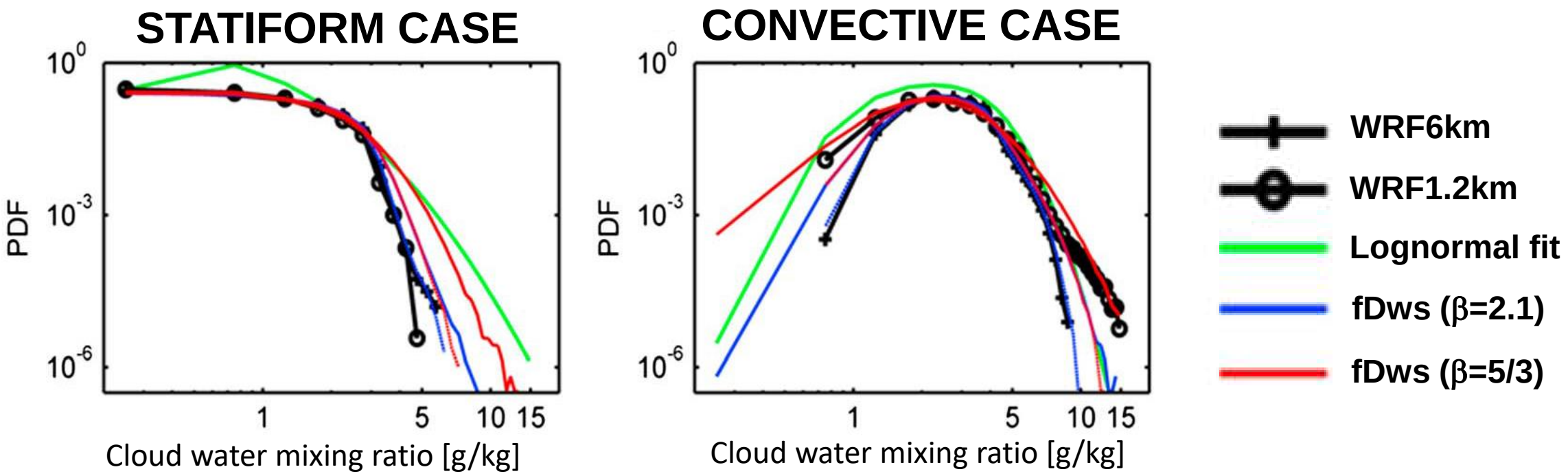
fDws methodology

Nogueira & Barros (2014, JGR Atmos.)
Nogueira (2018, Earth System Dynamics)



Spatial Stochastic Fractal Downscaling of Clouds

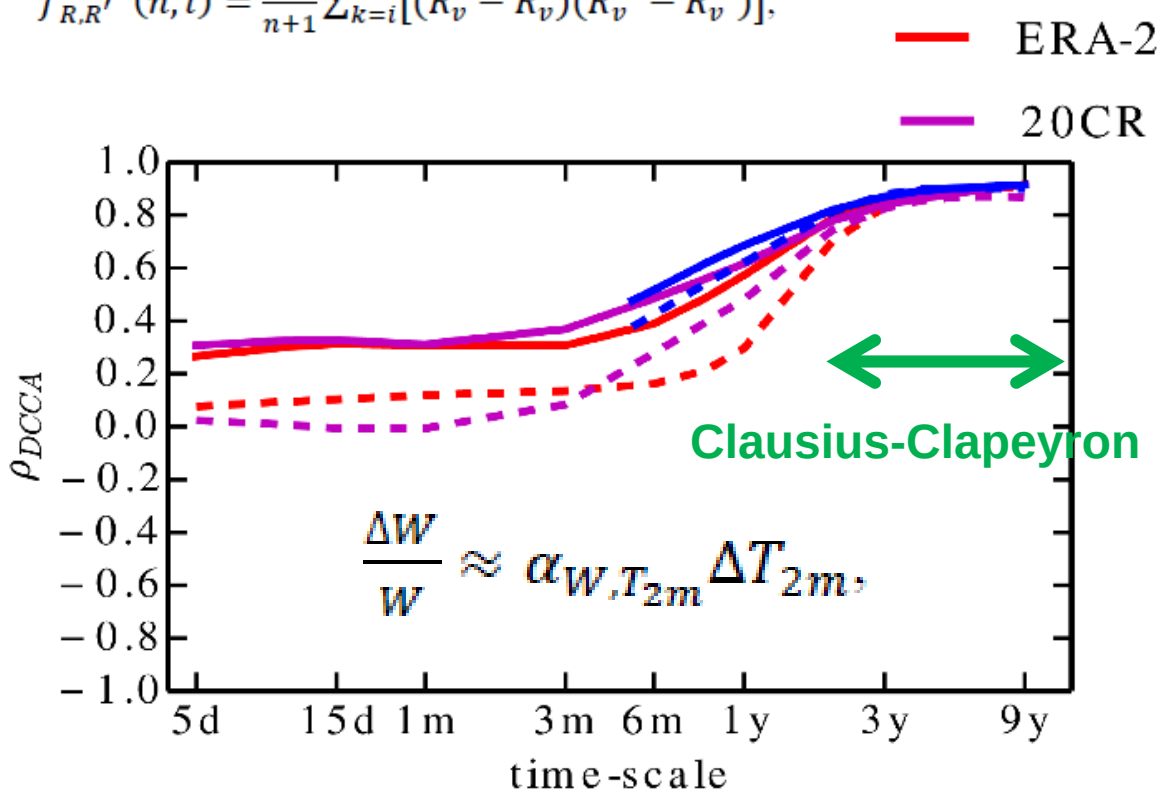
PDFs STOCHASTIC DOWNSCALING ⇔ PDFs DYNAMICAL DOWNSCALING



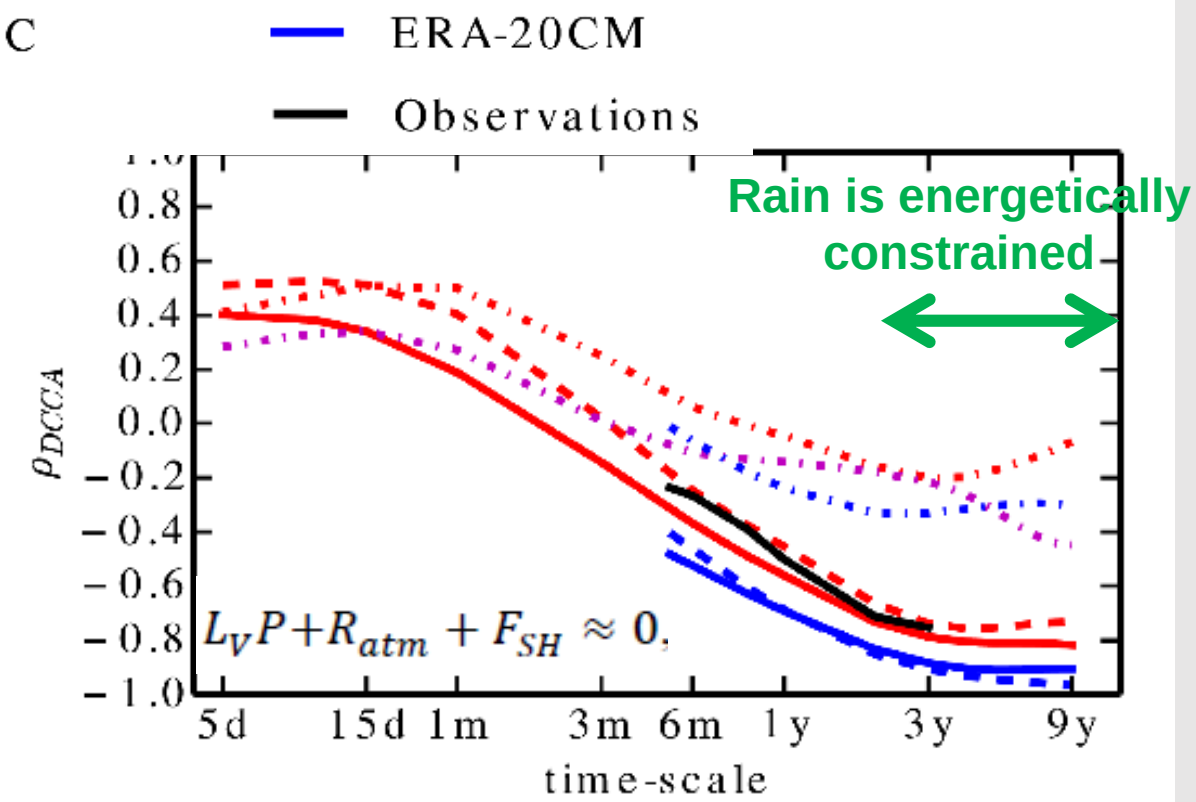
Temporal Fractal Downscaling of Rain: Predictors

Employ Detrended Cross-Correlation Analysis to find key PREDICTORS

$$f_{R,R'}{}^2(n,i) = \frac{1}{n+1}\sum_{k=i}^{i+n}\left[(R_v - \widetilde{R_v})(R_v{}' - \widetilde{R_v}')\right],$$



a) Precipitable water vapor vs T_{2m} (solid); Precipitable water vapor vs SST (dahsed)

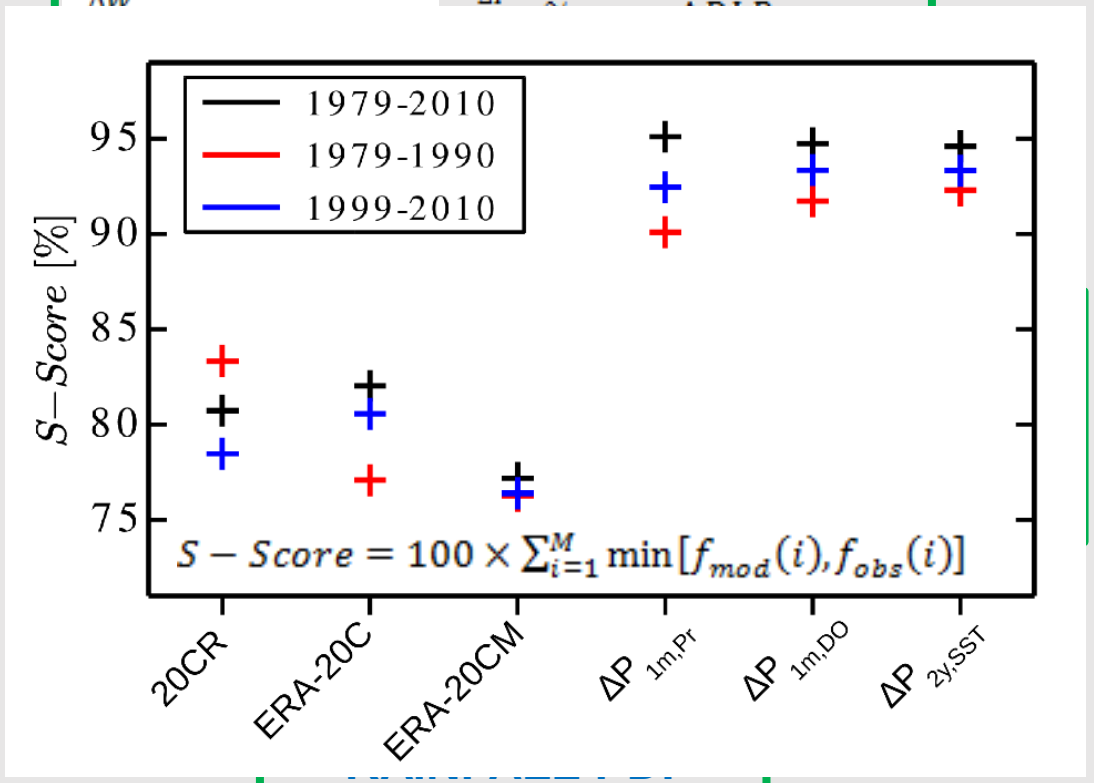


b) Rain vs R_{ATM} (solid); Rain vs DLR (dahsed); Rain vs SH_{flx} (dot-dahsed)

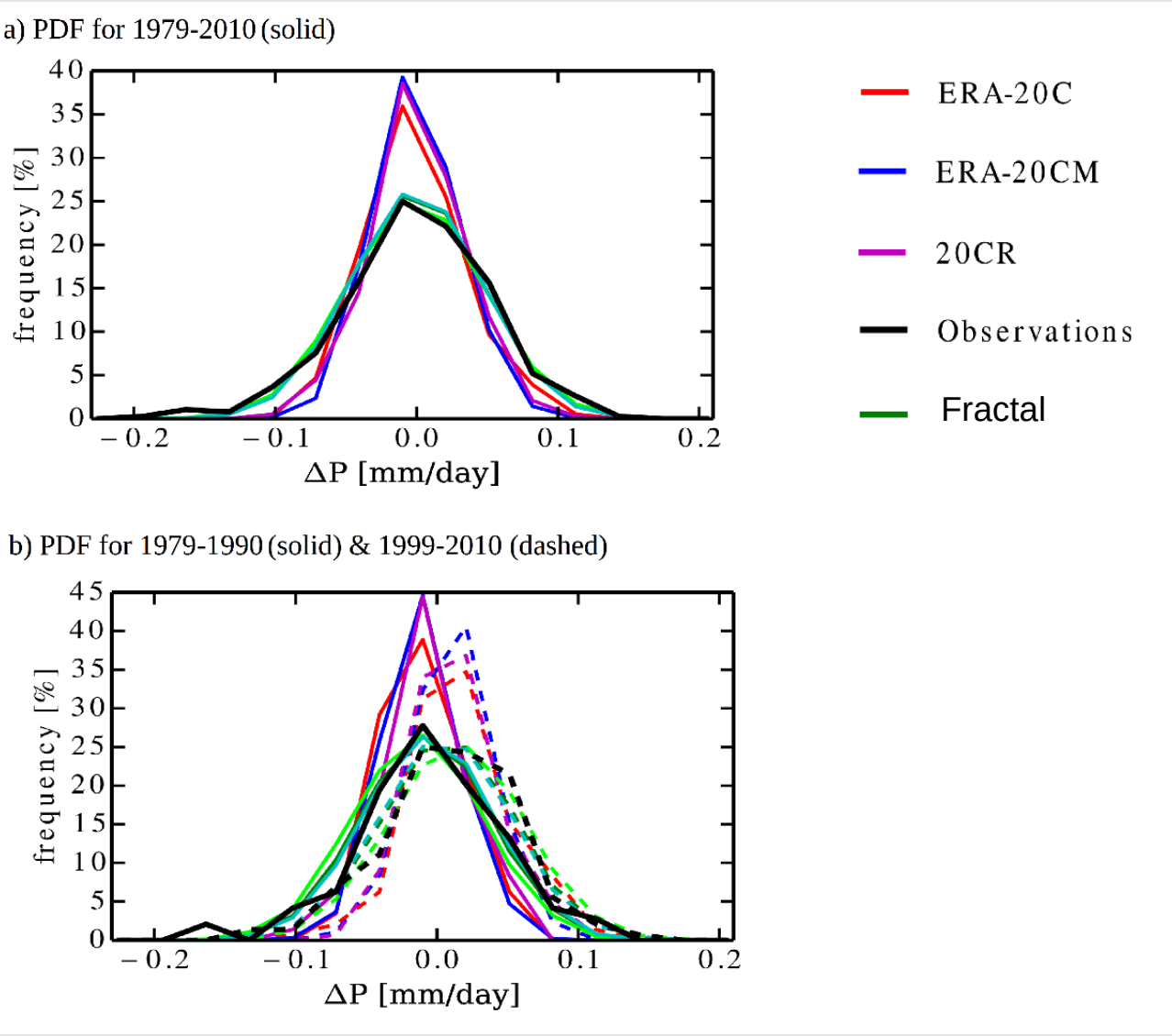
Nogueira (2018, Clim. Dyn) & Nogueira (2018, Earth. Syst. Dyn)

Temporal Fractal Downscaling of Rain: Application

COMPUTE 3-YEAR VARIABILITY FROM ENERGETIC CONSTRAINTS AND CLAUSIUS-CLAPEYRON



Nogueira (2018, Earth Syst. Dyn.)



SUMMARY & THE WAY AHEAD

- Dynamical downscaling is a key tool for weather and climate;
- But very high (~km) resolutions are often required;
- Stochastic methods can increase resolution at low computational cost;
- Stochastic methods can calibrate the comprehensive simulations (which have intrinsic model limitations and high-resolution);
- Fractal downscaling can do both; can be combined with other methods (e.g. copulas)

Next:

- Combine stochastic downscaling with dynamical for Madeira, Azores & Extreme events over Portugal= hybrid dynamical/stochastic EPS;
- Extend the DCCA predictor analysis in these studies;
- Systematic (Offline) Coupling to CMIP6, CORDEX
- FOCUS 1: Quantify risk of extremes (Weather & Climate);
- FOCUS 2: Madeira & Azores Islands – high-resolution ensemble data