Global Diagnostics of the Effective Resolution of GPM Retrievals:

how well are we doing and where do we need improvements?

Efi Foufoula-Georgiou, Clément Guilloteau

Chris Kummerow, Pierre Kirstetter

A Very Basic Question

At what spatial scale can we "trust" the GPM products?

Motivation: Basic questions

1. *What is the **"finest scale at which retrievals accurately reproduce the local spatial variability of a reference product?"*** (= Effective Resolution: ER)

2. ***What is the ER of the current GPROF-2017 retrievals?***
   -- How is it spatially distributed over land, oceans, snow-covered areas, storm regimes, etc.?
   -- Are there unexpected results and why?
   -- How can ER serve as diagnostic tool to improve retrieval algorithms?

Effective Resolution: far from trivial

The grid size is often referred as the “resolution” of the product, BUT in fact it does not ensure the ability to resolve precipitation patterns at the corresponding scale.

ER is a result not only of the nominal resolution of the instrument, but also of the information content of each MW channel and the ability of the retrieval algorithm to accurately interpret this information to reproduce the precipitation variability and structure at fine scale

Effective Resolution (ER): how to compute?

1) Object-based methods

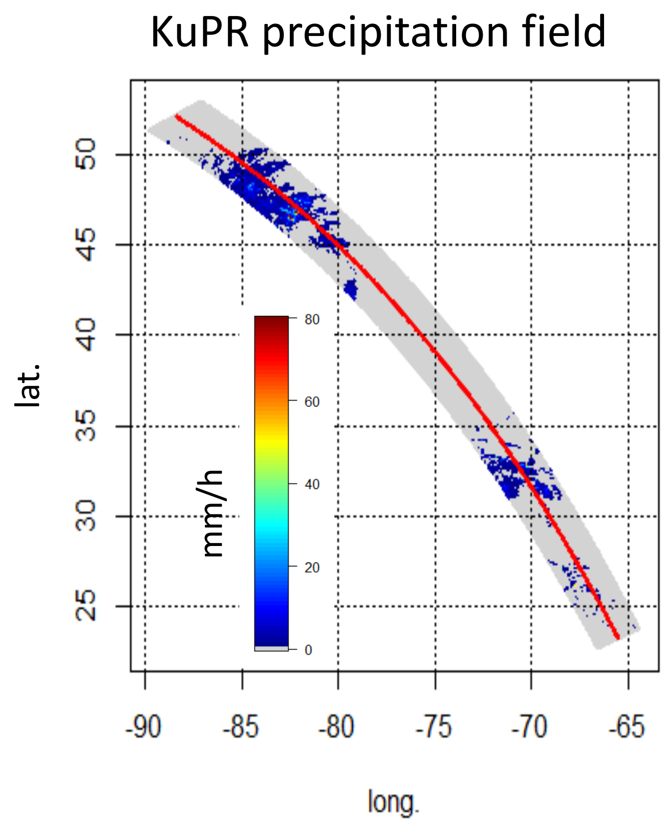
-- use thresholds to define "objects"
-- compare object attributes: size, convexity, compactness, etc.
-- must repeat for several thresholds
-- computationally expensive and hard to interpret

2) Spatial multi-scale decomposition via wavelets

-- A wavelet is a differential filter: WCs= local gradients
-- Discrete Orthogonal Wavelet

- Erases spatial correlation of analyzed signal
- Removes possible non-stationarities
- Characterizes each scale in a non-redundant way
- Reconstructive basis: all info about original signal kept in WCs
- Var(WCs)= Wavelet spectrum= how energy is distributed across scales

Determining ER: Basic 1D example



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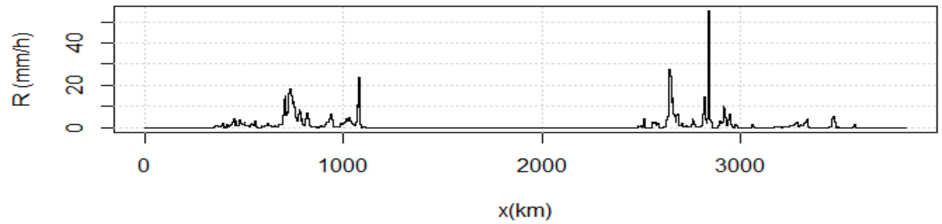
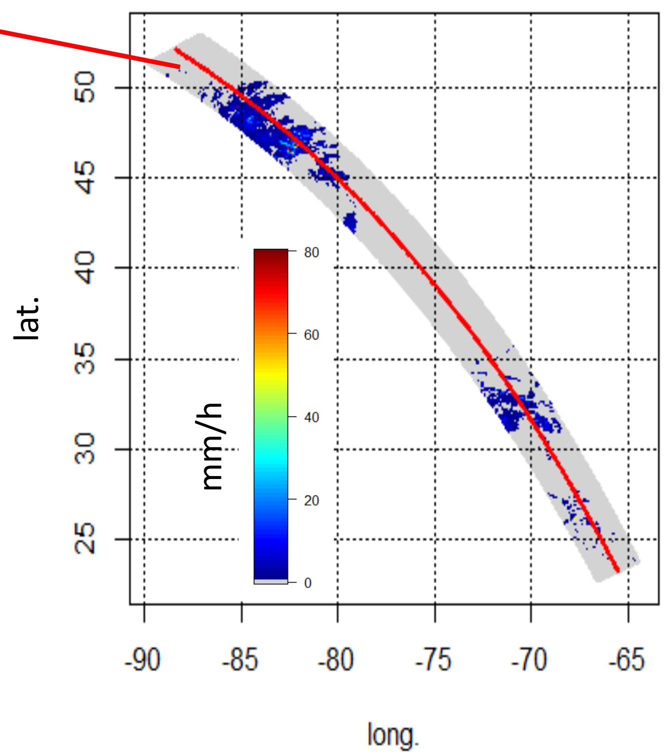


transect

KuPR precipitation field



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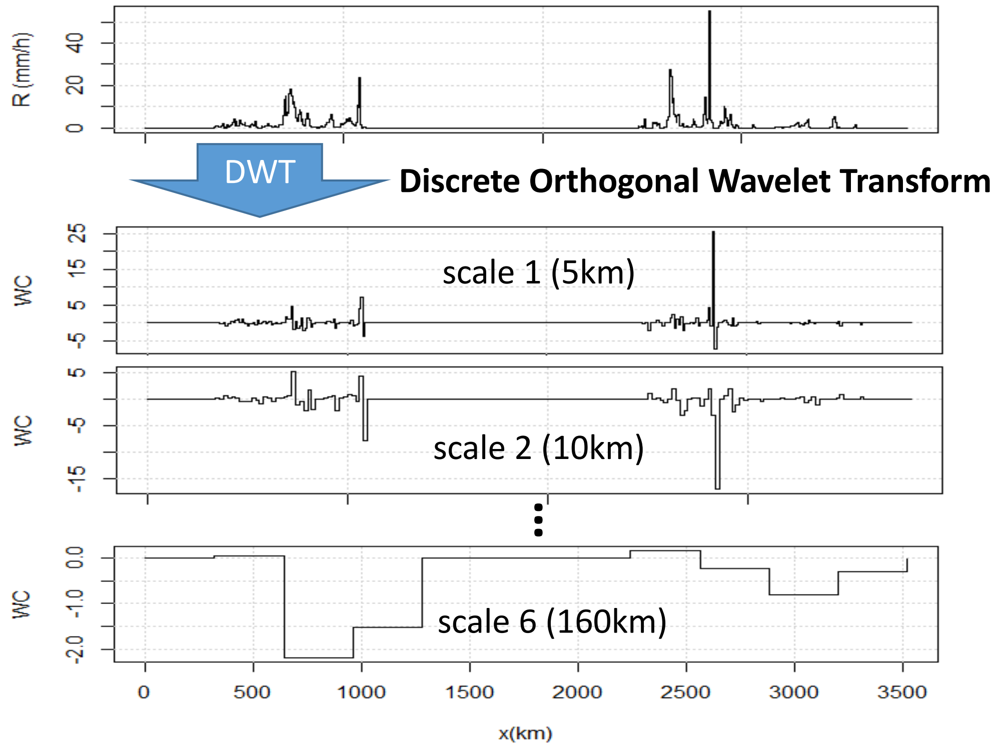

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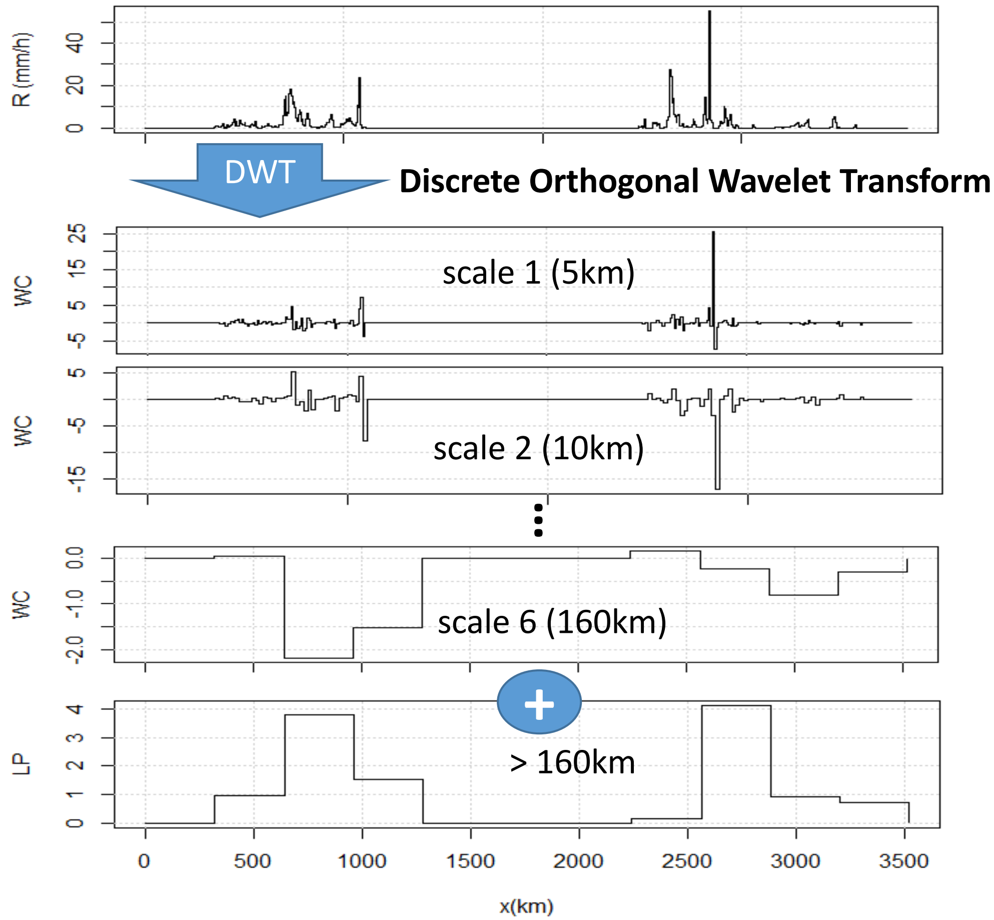

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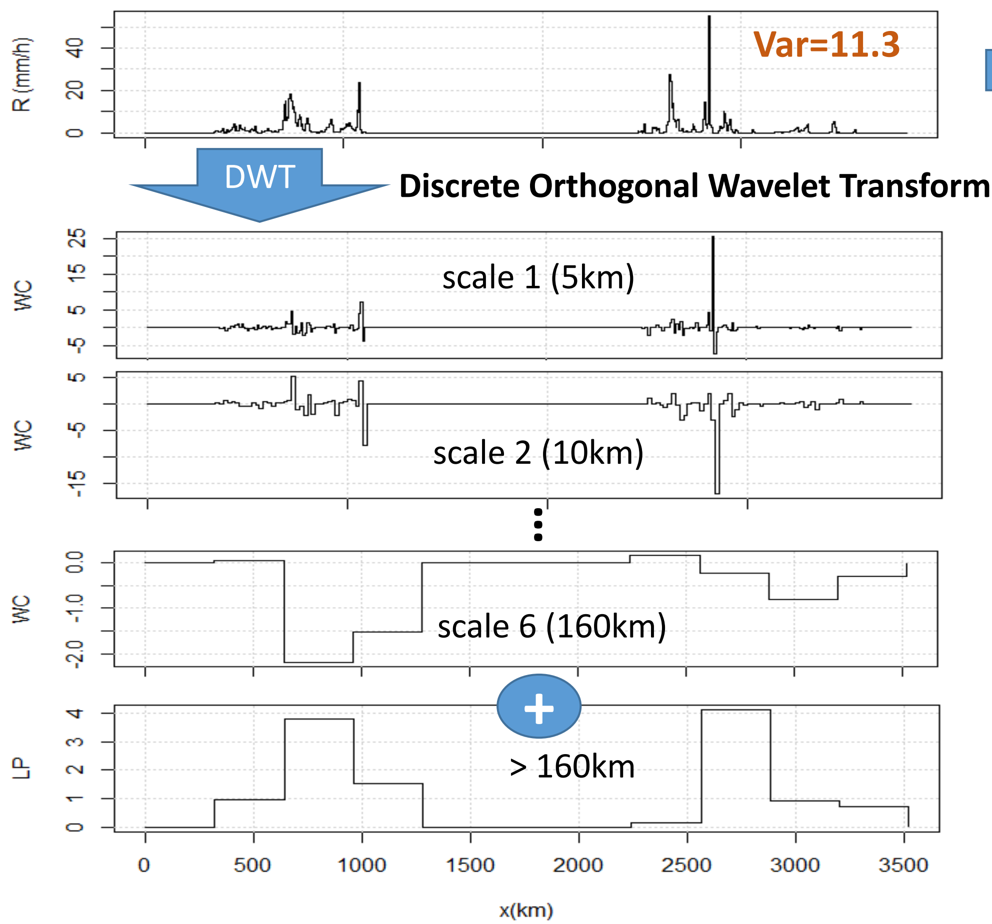

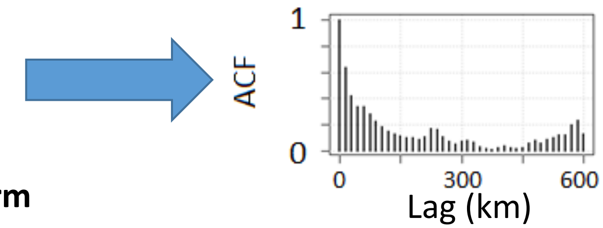

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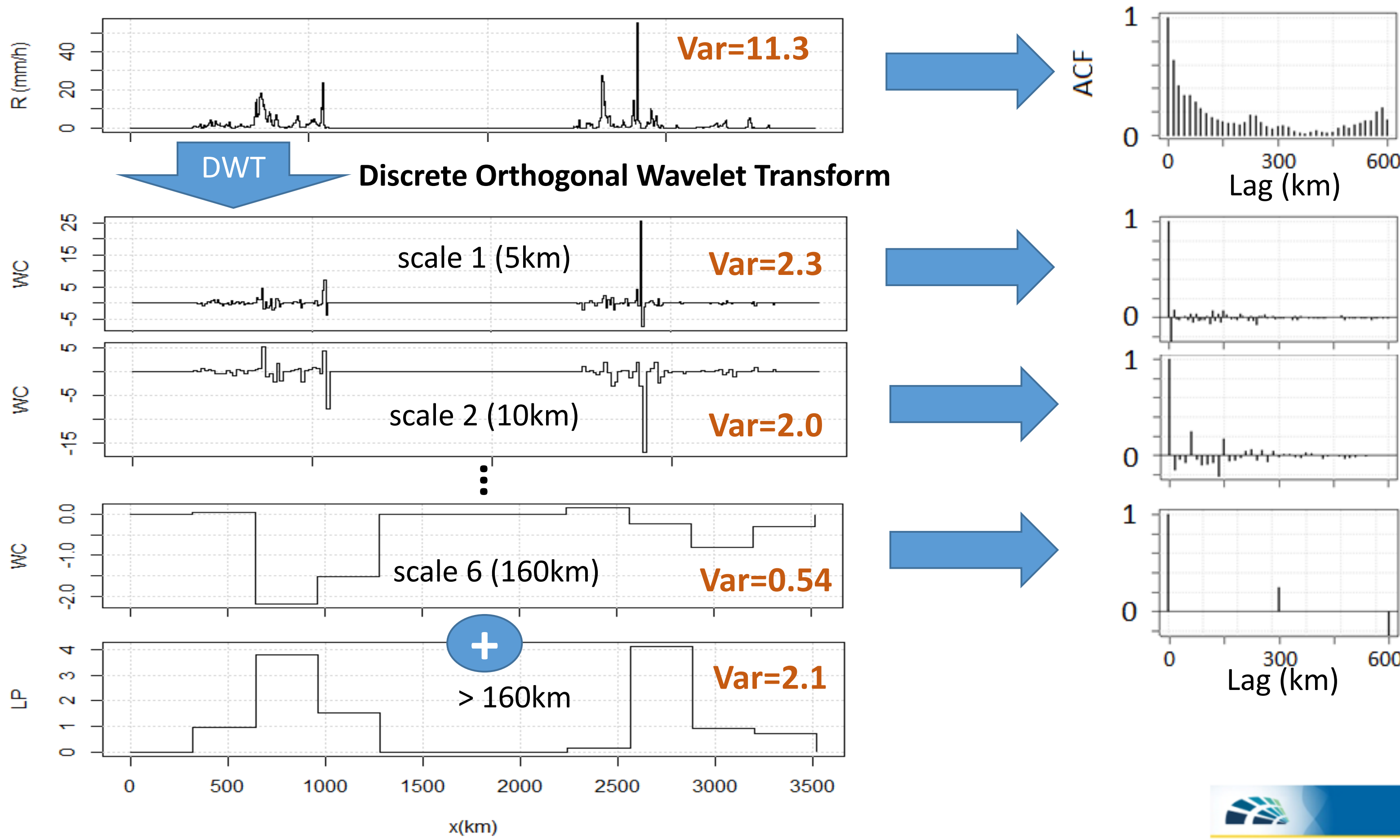

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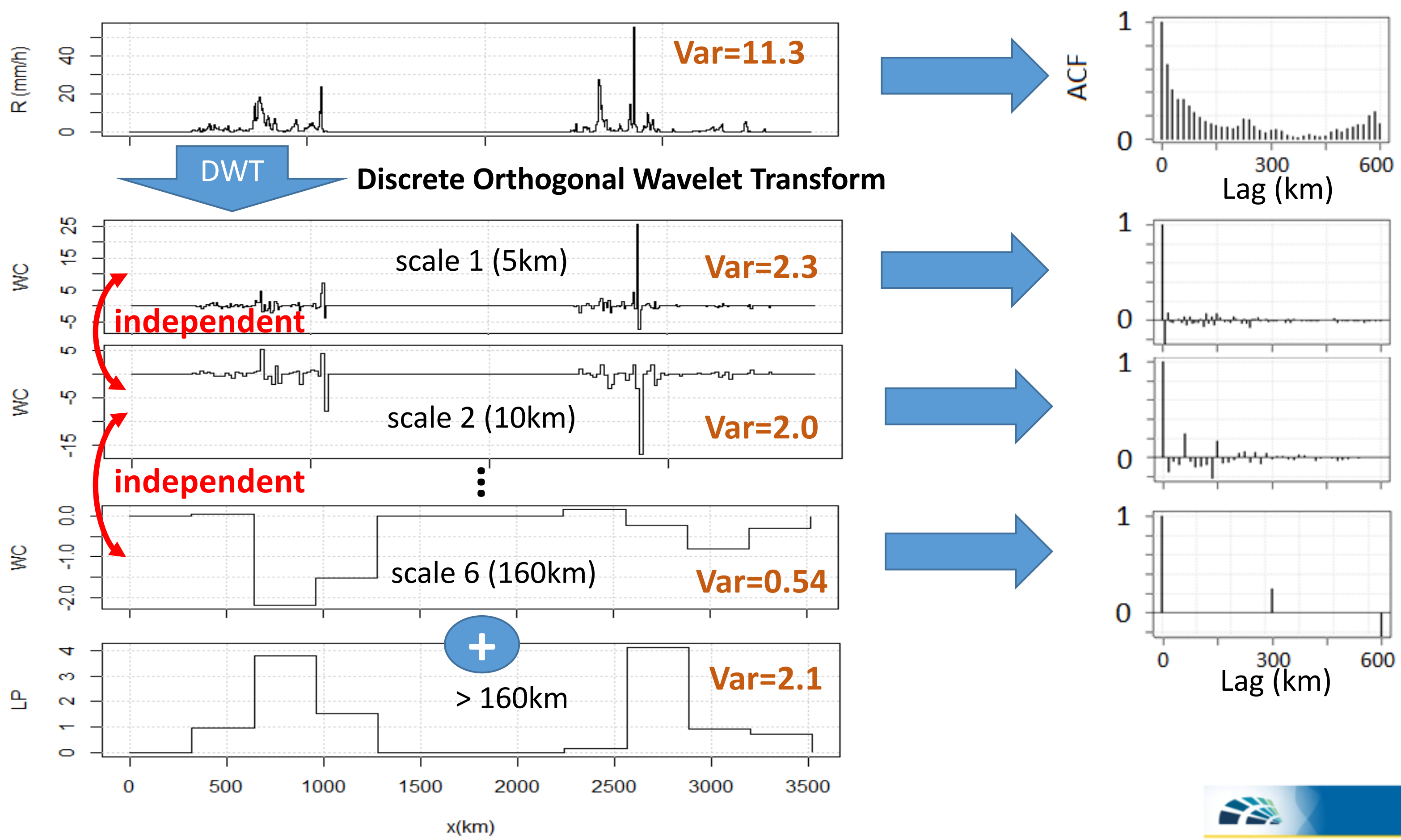

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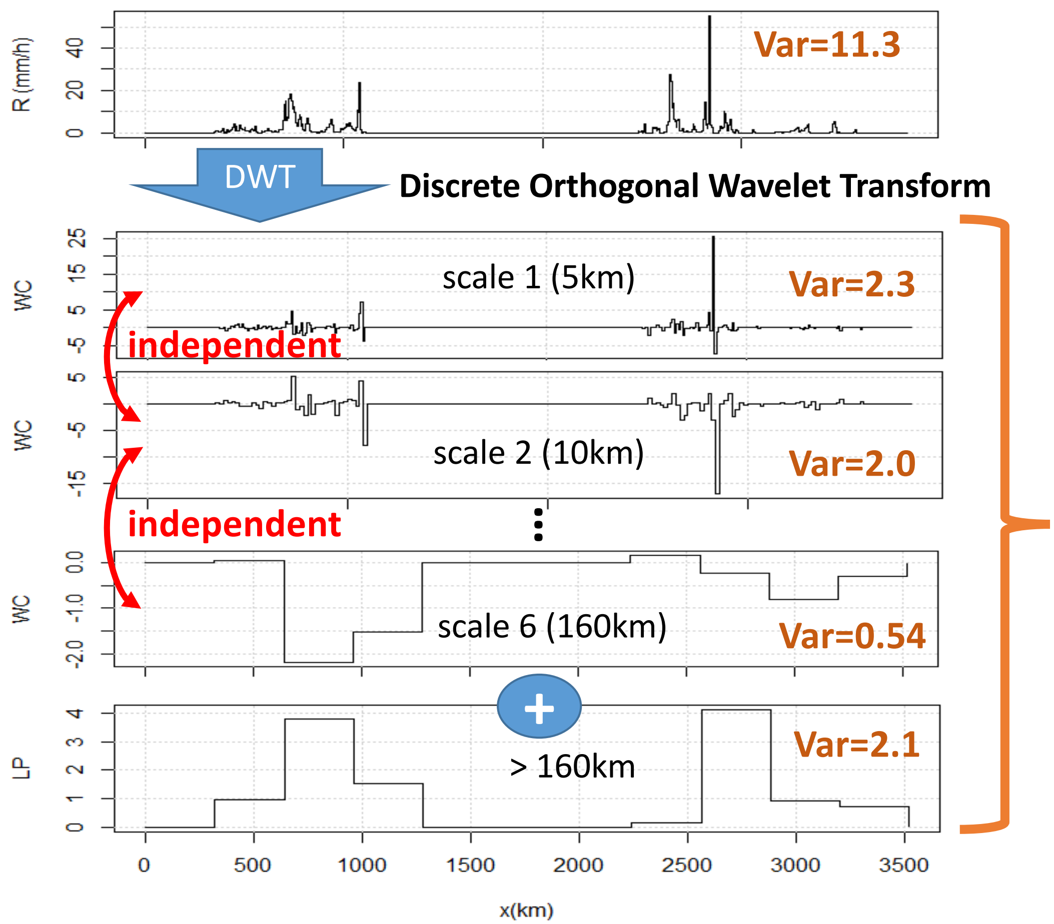
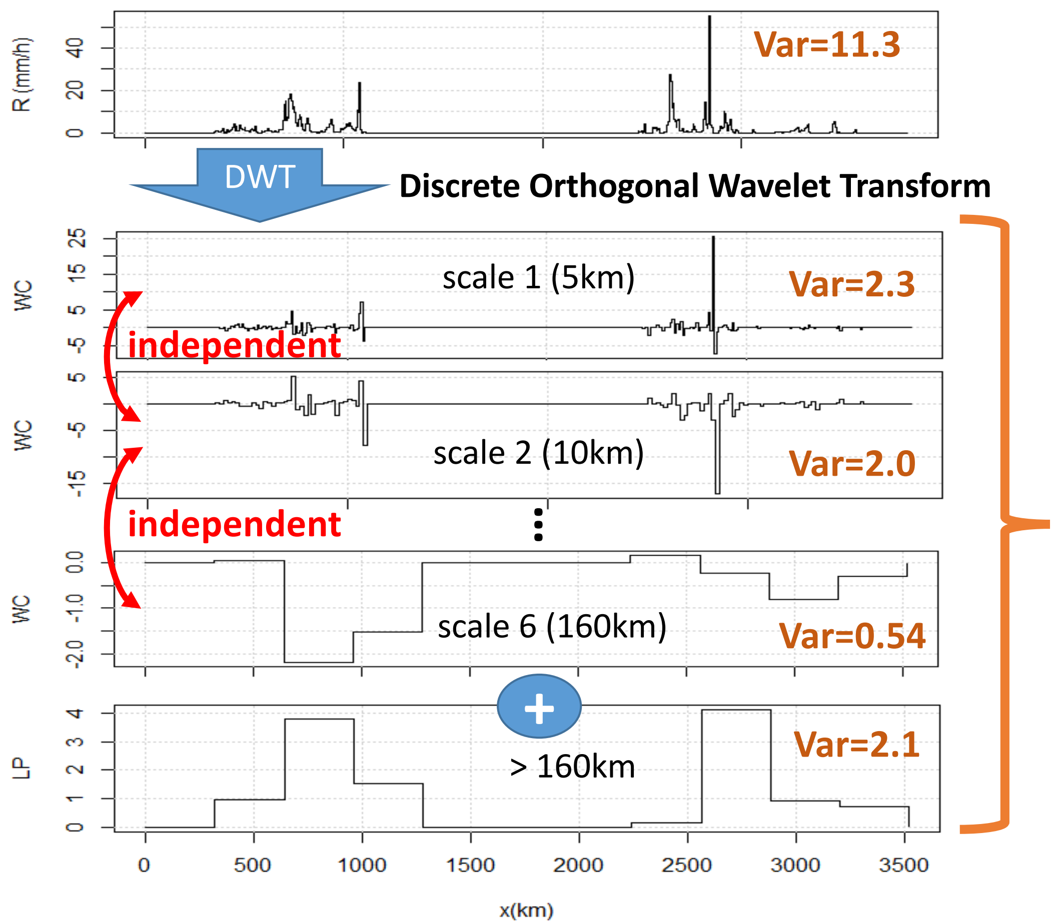
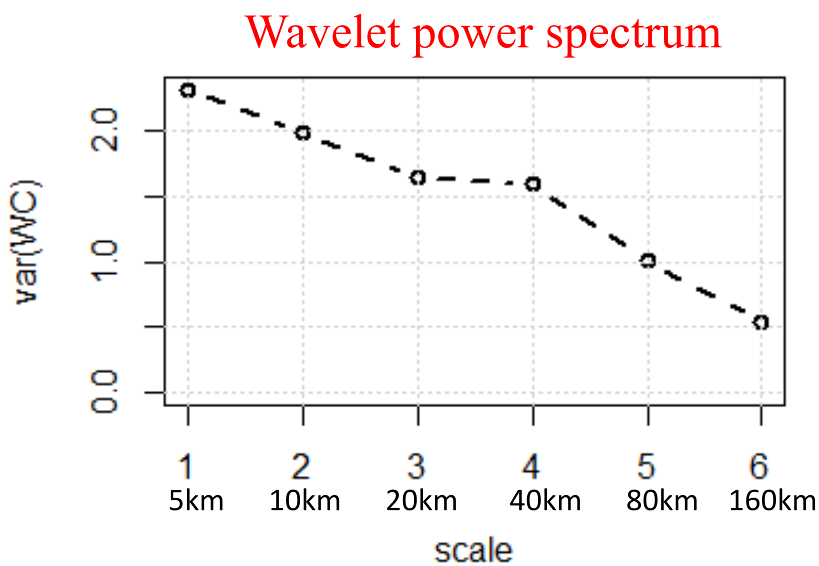


$$\text{var(signal)} = \text{var(LP)} + \sum_{\text{scale}=1}^{6} \text{var (WC)}$$

Determining ER: Basic 1D example



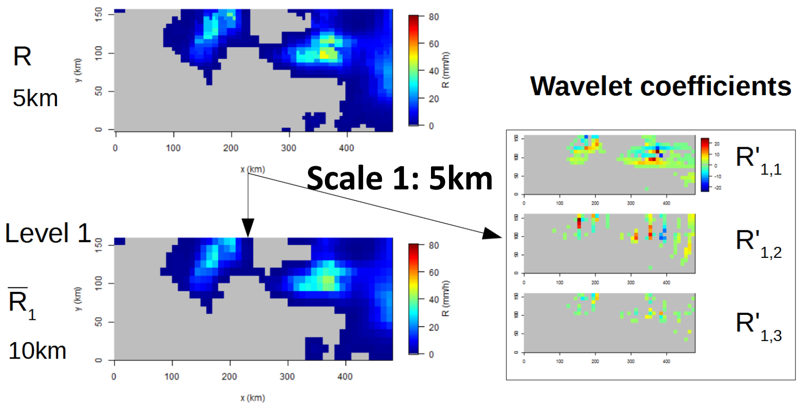


Shows how the variance of the signal is distributed across scales.

Determining ER: 2D

- In two dimensions the principle remains the same.
- Three series of wavelet coefficients are extracted at each scale (3 directions)

(Kumar and EFG, Rev. Geophys., 1997)



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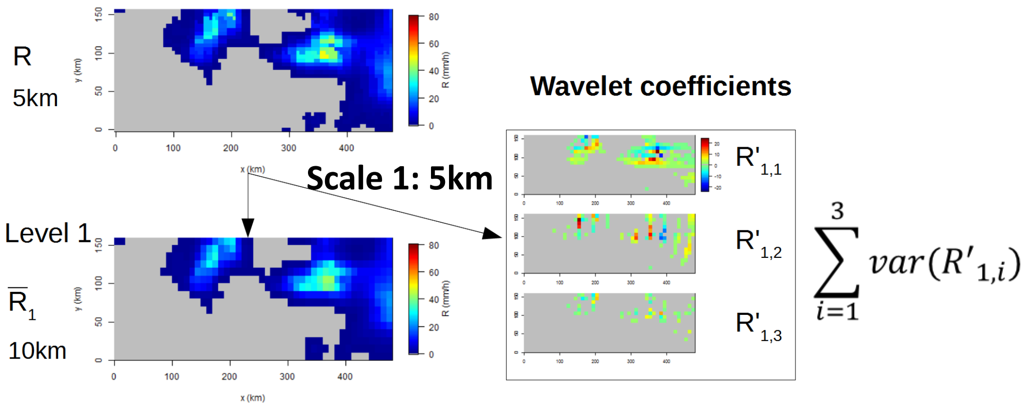

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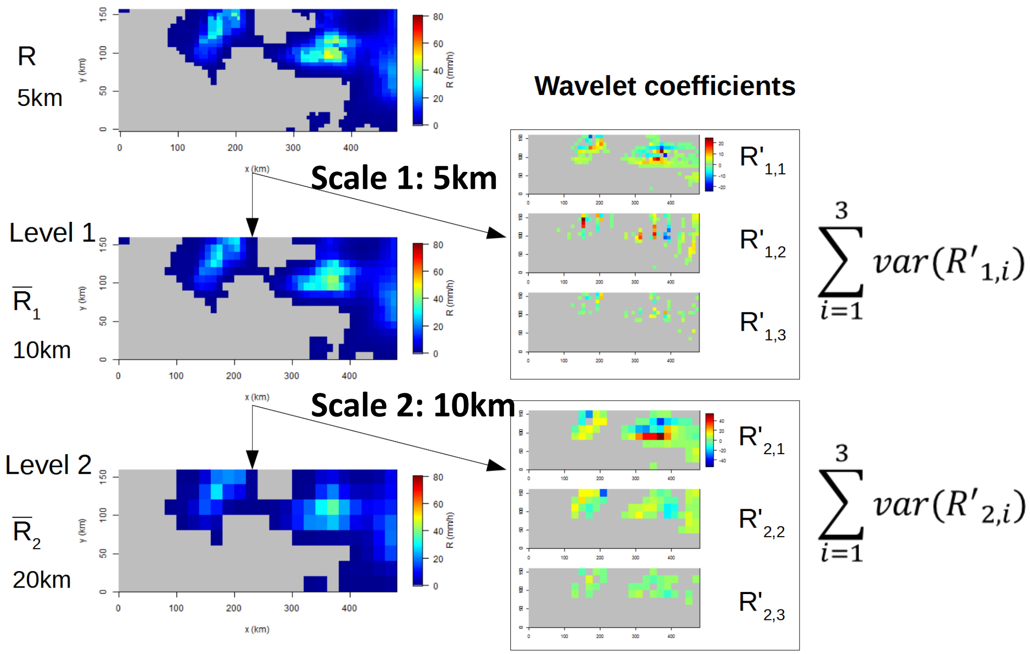

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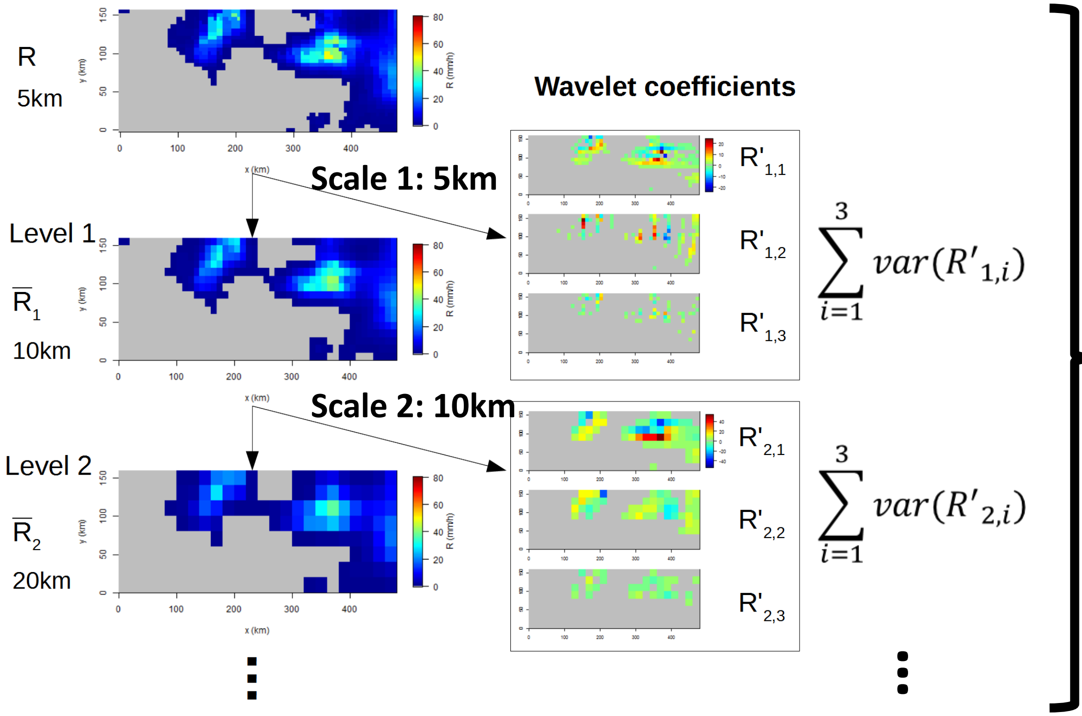
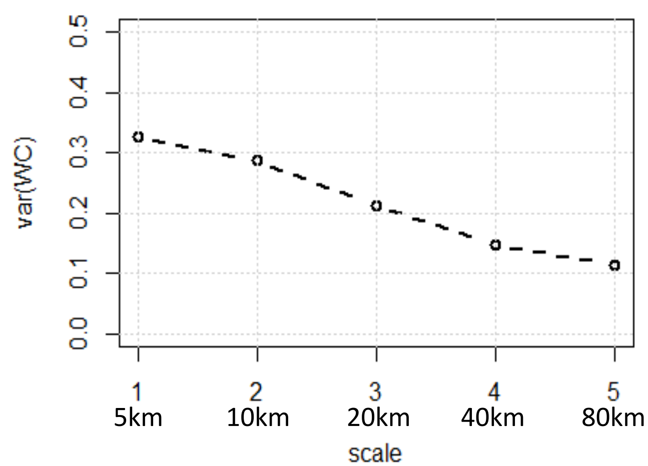


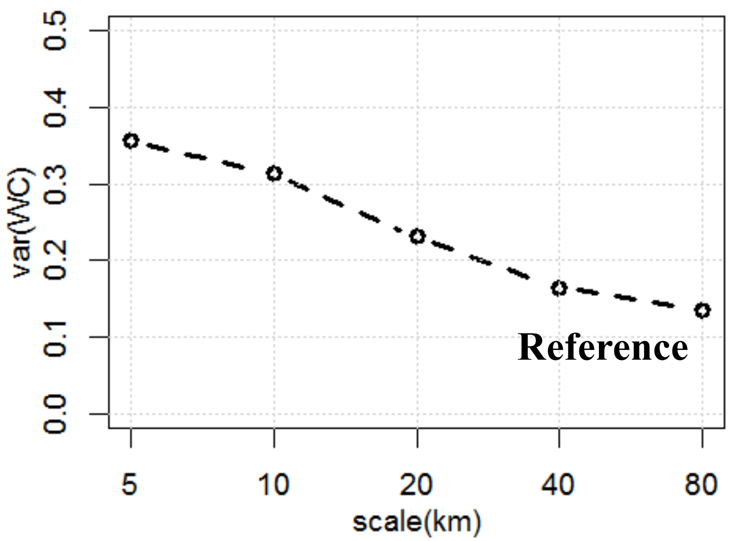
2D wavelet power spectrum



Comparing Retrievals to a Reference Field

2D spectrum of the Reference field

e.g., average spectrum from one year of radar (MRMS) observations over South-Eastern US



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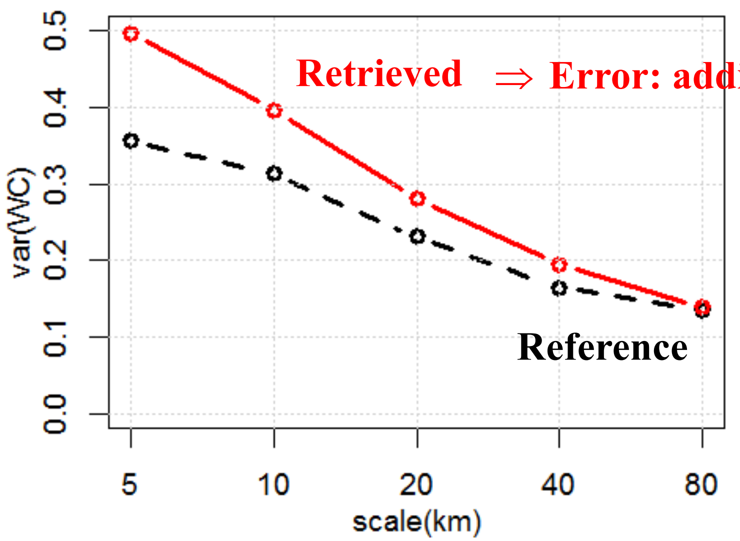
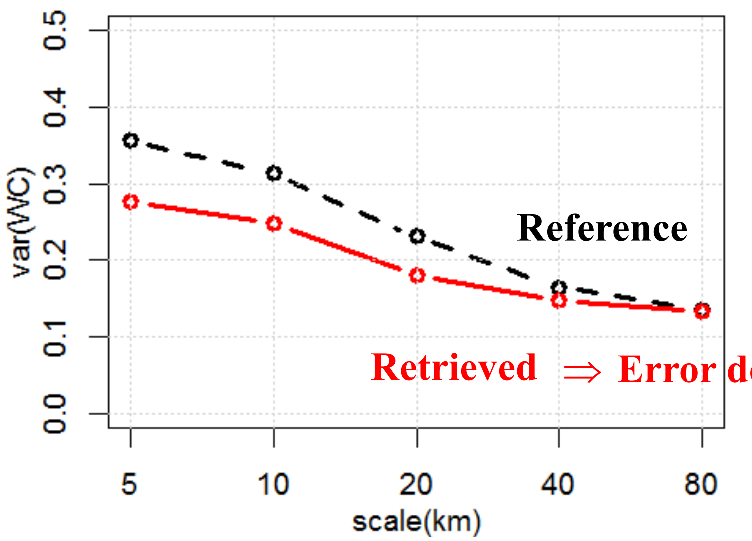


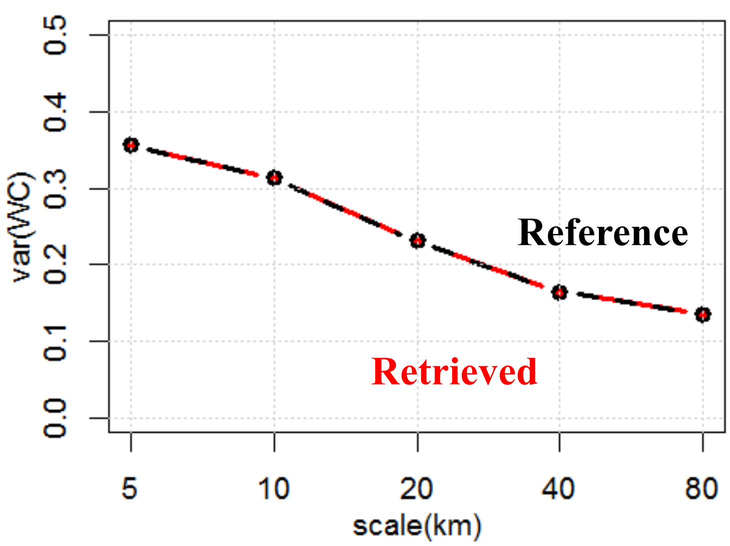
⇒ Error: additive random noise, bias, or High Frequency Noise

Comparing Retrievals to a Reference Field



$\Rightarrow$ Error depends on Reference (conditional bias)

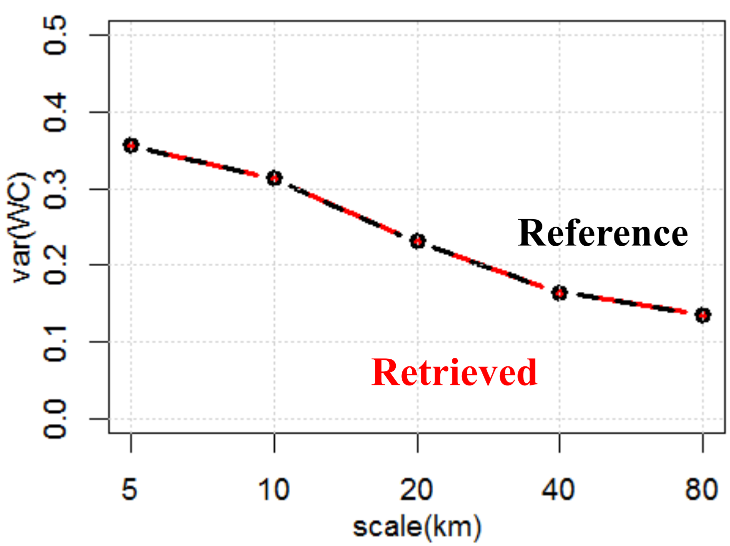
Comparing Retrievals to a Reference Field



Comparing Retrievals to a Reference Field

$$R'_{MW} = R'_{ref} + \varepsilon'$$

$$var(R'_{MW}) = var(R'_{ref}) + var(\varepsilon') + 2\,Cov(R'_{ref}, \varepsilon')$$



Perfect Retrieval?

Comparing Retrievals to a Reference Field

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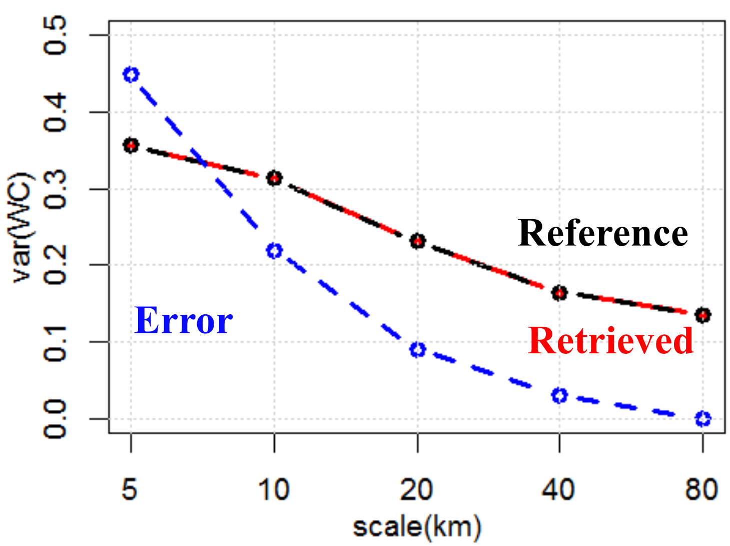


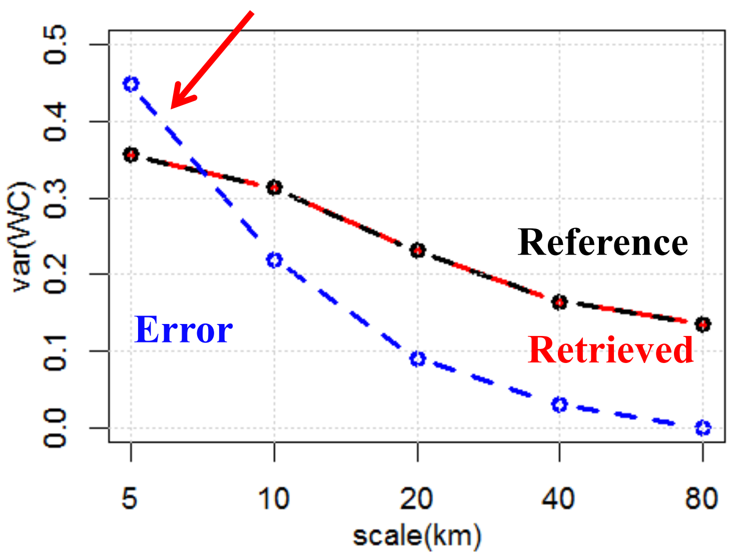
Perfect Retrieval?

Not yet!
Need to look at the WCs of
Error field = Retrieval – Reference

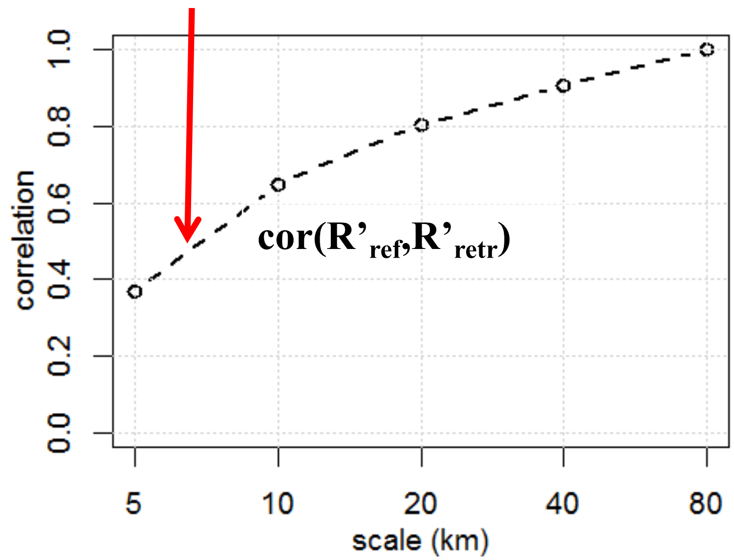
& Correlation (Reference, Retrieval)

Comparing Retrievals to a Reference Field

Large error at small scales



Poor local correlation at small scales



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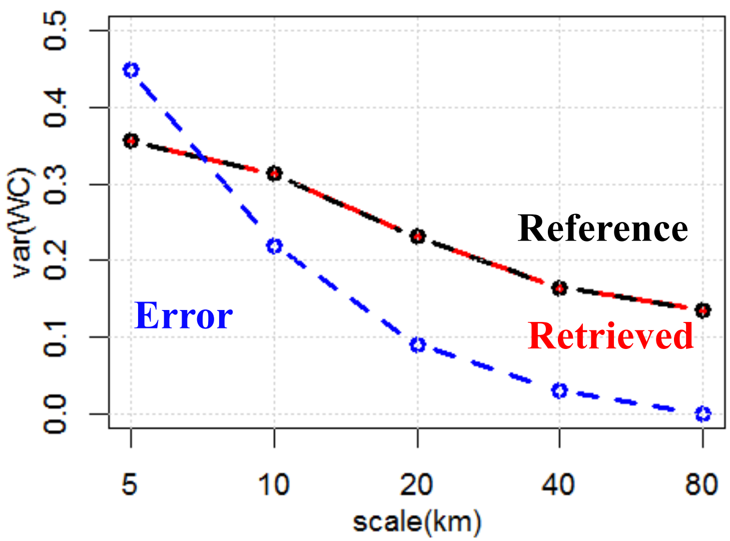
Defining Effective Resolution (ER)

Select a criterion to determine which scales are well retrieved (ER)



Signal:Noise ratio > 2:1

$$var(Error') < \frac{var(Ref')}{2}$$

> 50% of local variability of Reference is explained by the Retrieval

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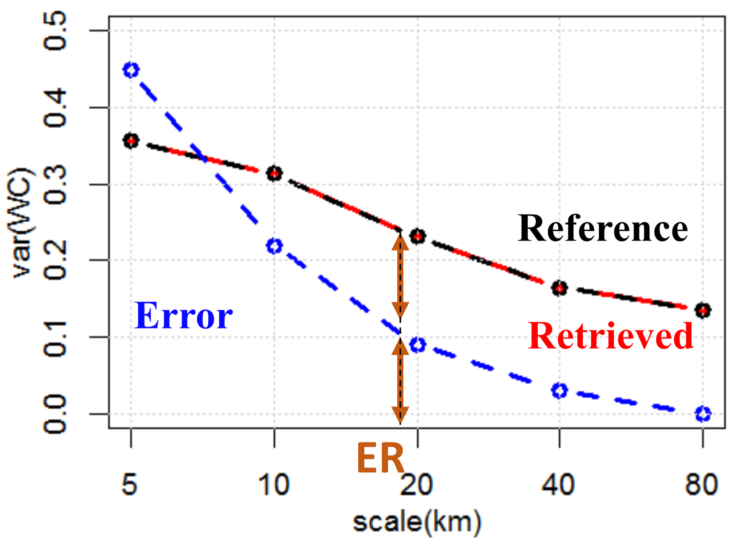

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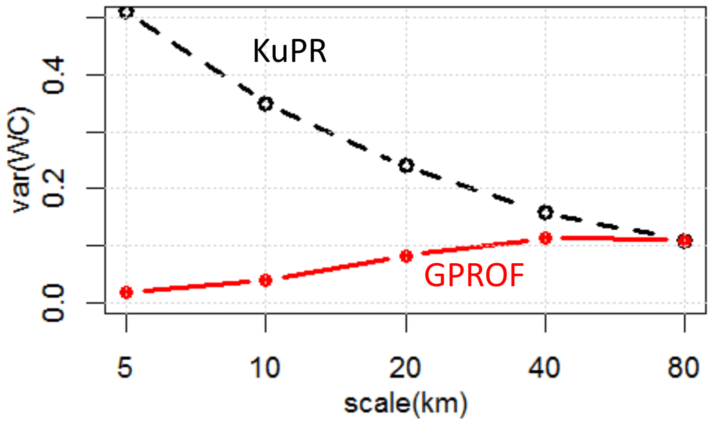
Global evaluation of GPROF-2017

- Three years of GMI retrieved precipitation globally analyzed against KuPR:

over oceans



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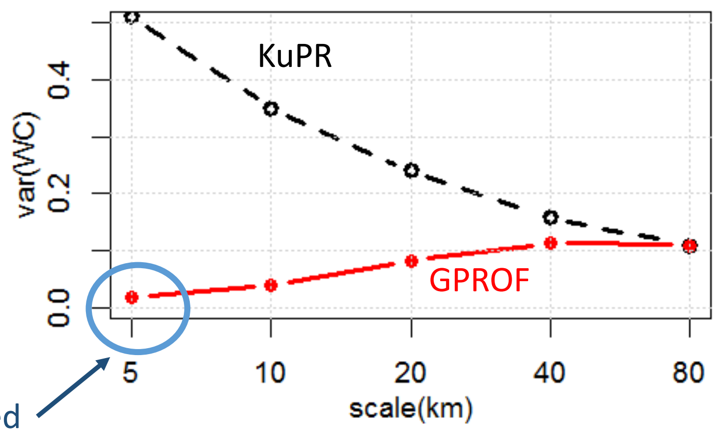

Interpolated from GPROF original grid

1. GPROF-2017 retrieval is smooth (as expected for a Bayesian retrieval)

2. The error is not independent from the reference rain rate.

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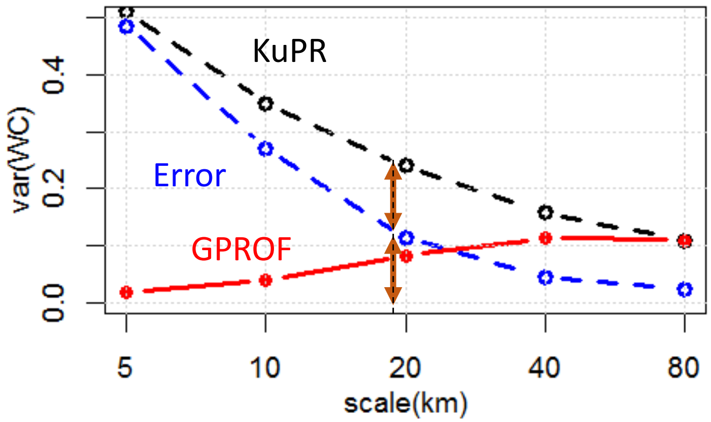

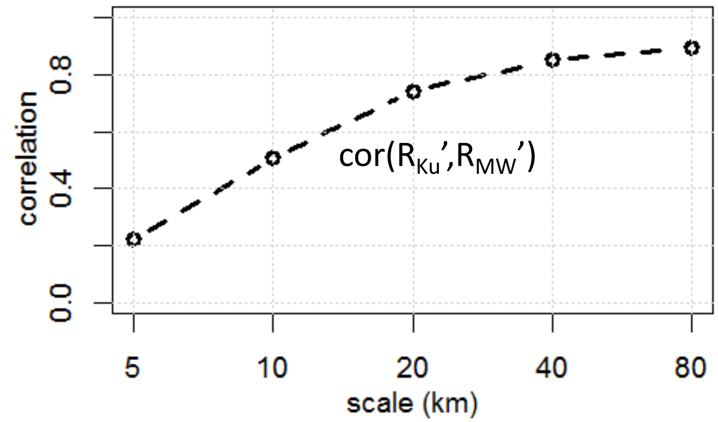

ER= 10-20Km

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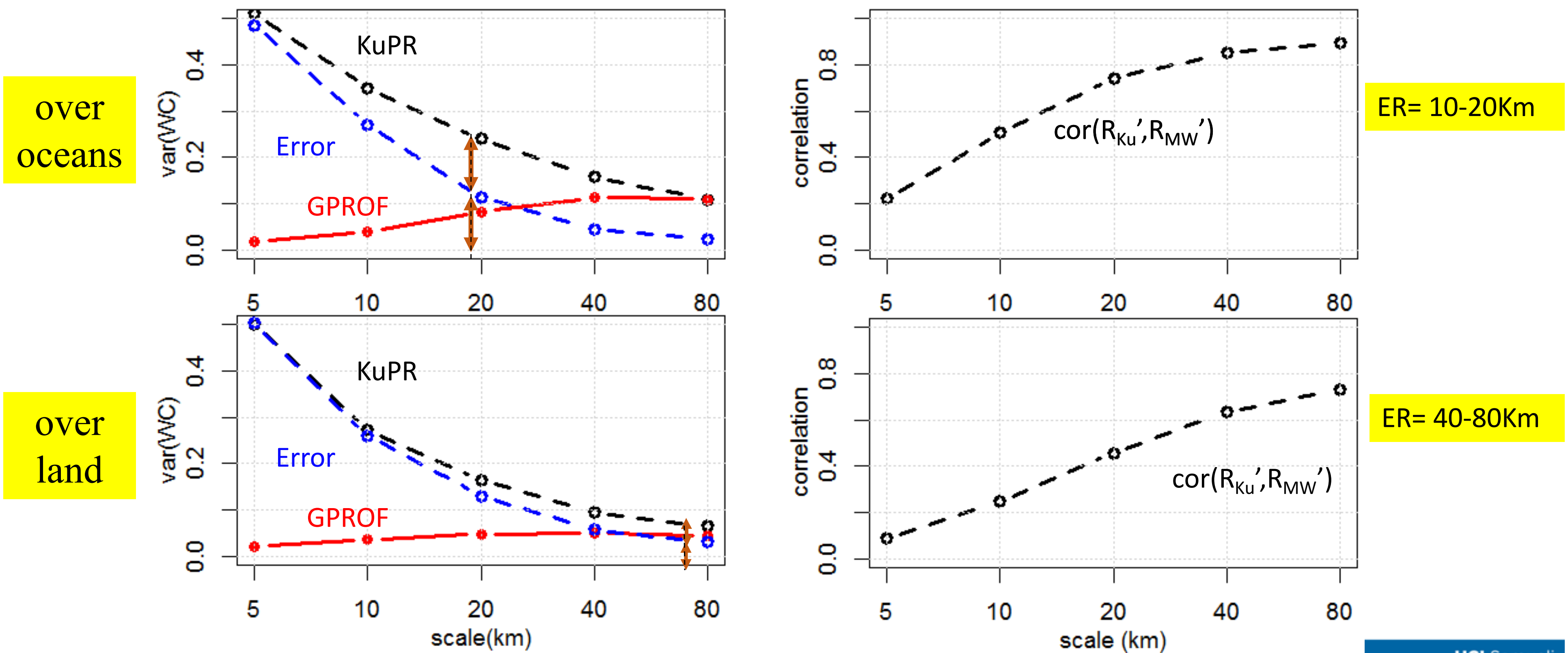
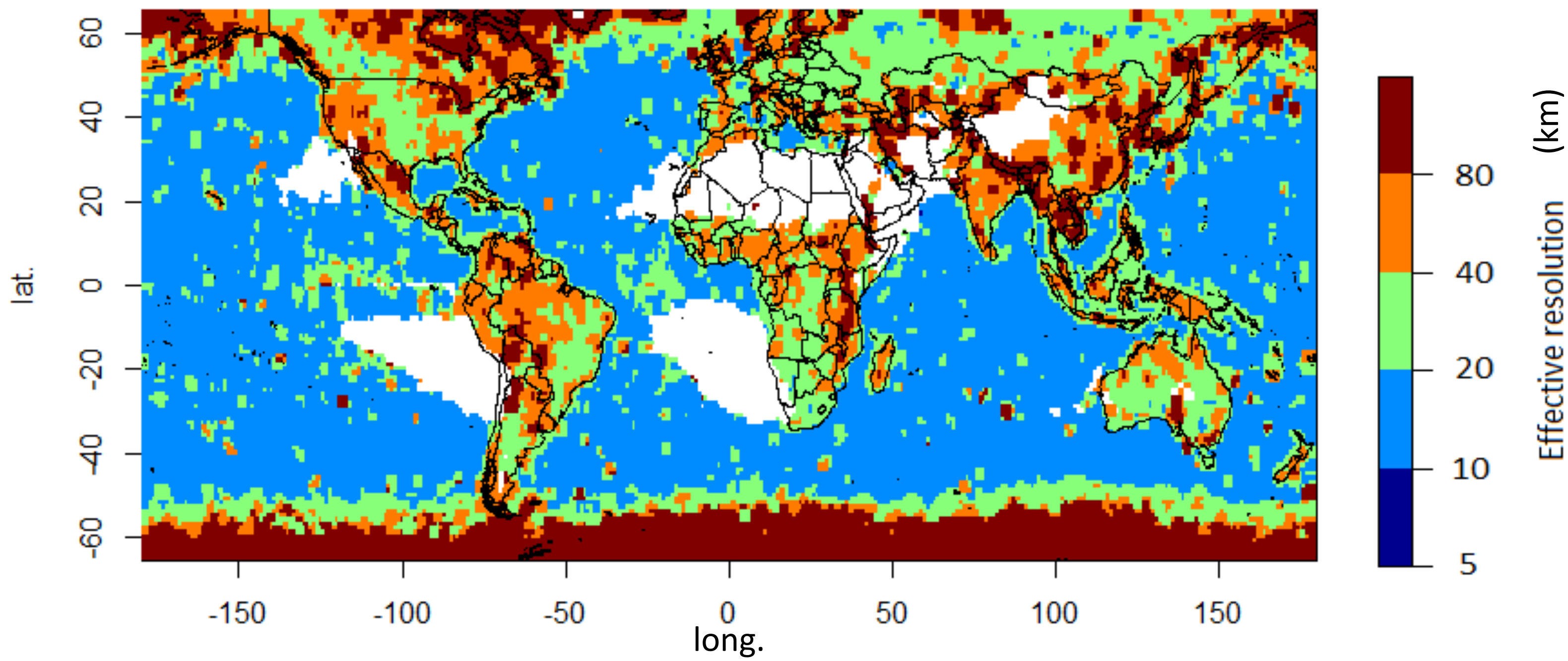


Global evaluation of GPROF-2017

- Global map of the effective resolution of GPROF-GMI vs KuPR



- Local values computed from all observations in 3°×3° boxes.
- March 2014 to February 2017: 16,500 GPM orbits

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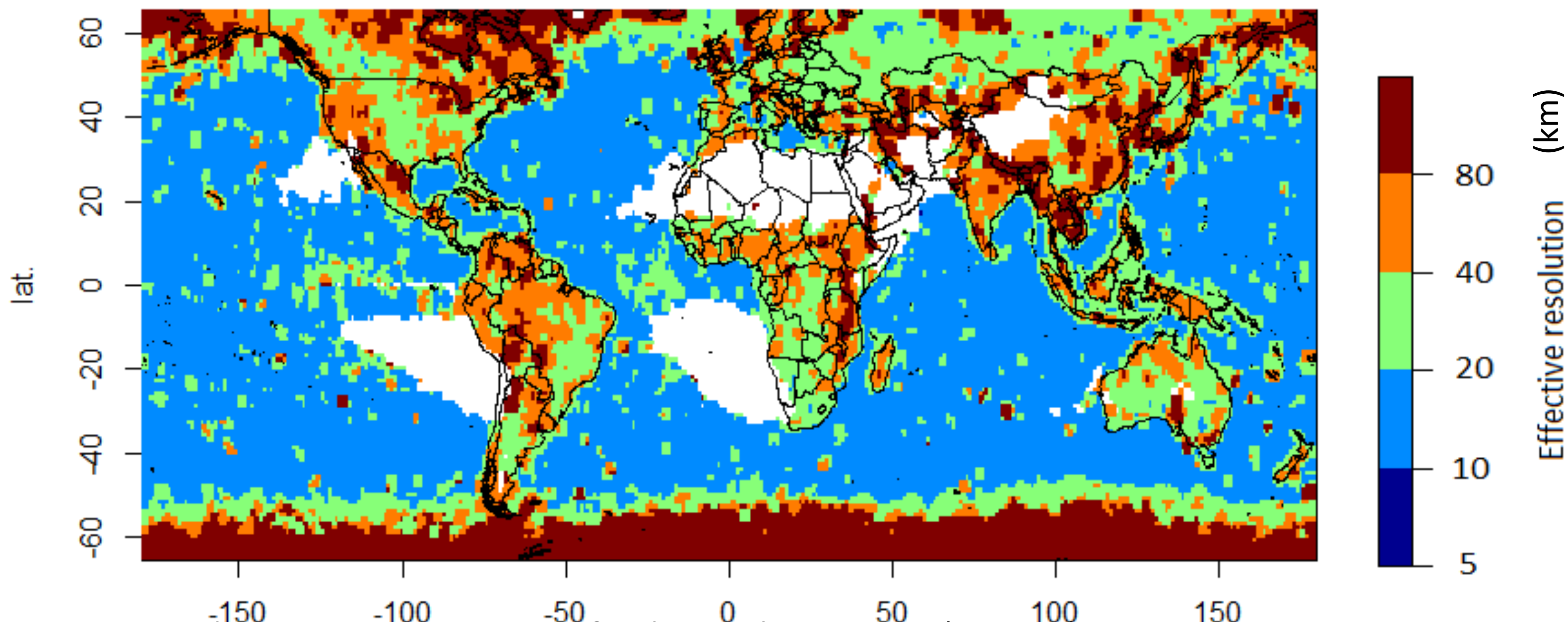
Global evaluation of GPROF-2017

- Global map of the effective resolution of GPROF-GMI vs KuPR



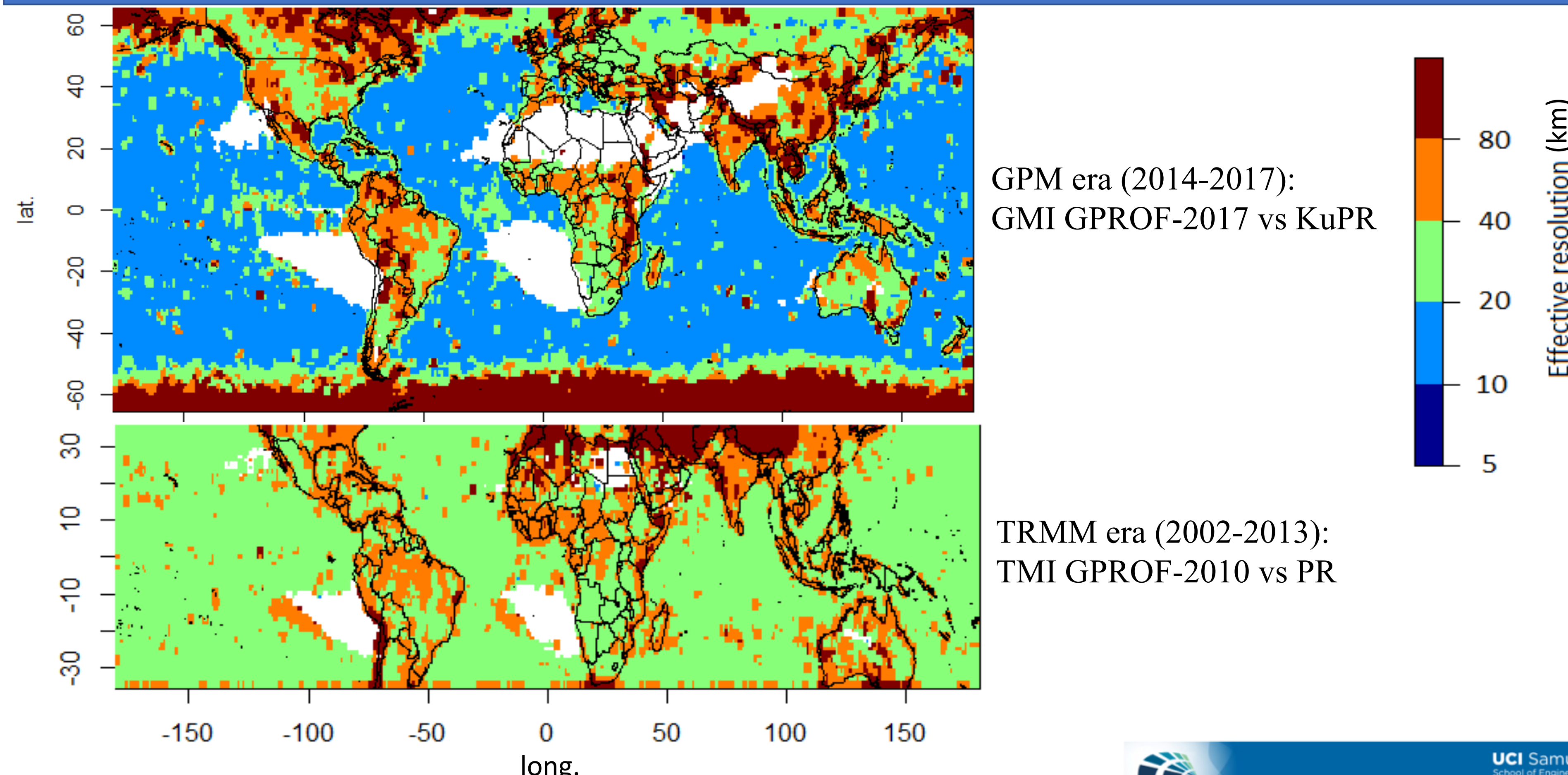
-Homogeneous results over oceans => Except for the southern ocean (sea ice?)

-Lower ER over land, much heterogeneity. ER>80km: Himalayas (mountains), South-East Asia, Coasts above 50° N.

-The retrieval seems to be performing as well in extra-tropical regions as in tropical regions.

-20~40km ER over land even in regions where deep convection is not dominant (e.g. Europe, Siberia …)

Global evaluation of GPROF-2017

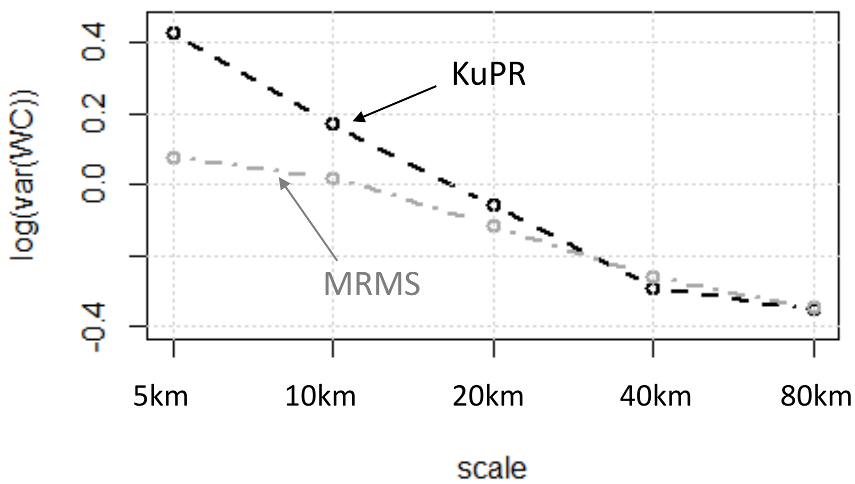


ER is a rigorous & robust framework

DIAGNOSTICS!

Evaluating the reference: KuPR vs MRMS

- One year of collocated KuPR and MRMS (gauge-adjusted radar) observations over Eastern US



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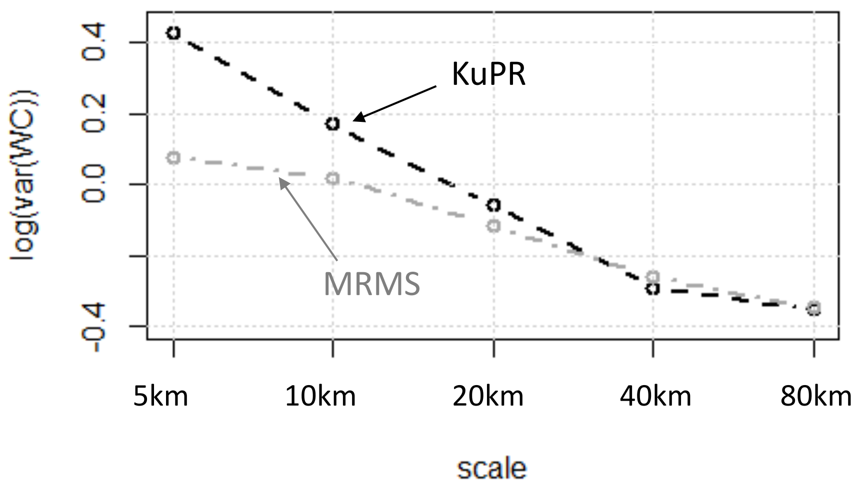

=> Does the KuPR overestimate fine scale variability ?
(may be due to overestimation of rain rates associated with deep convection)

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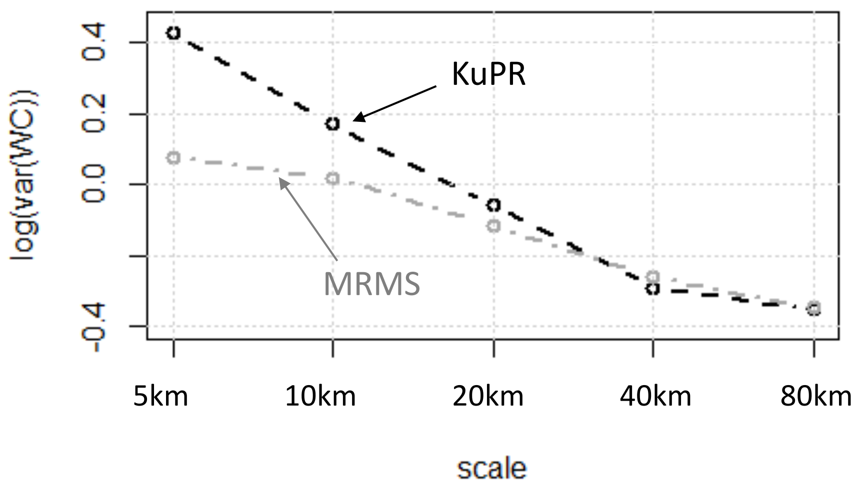

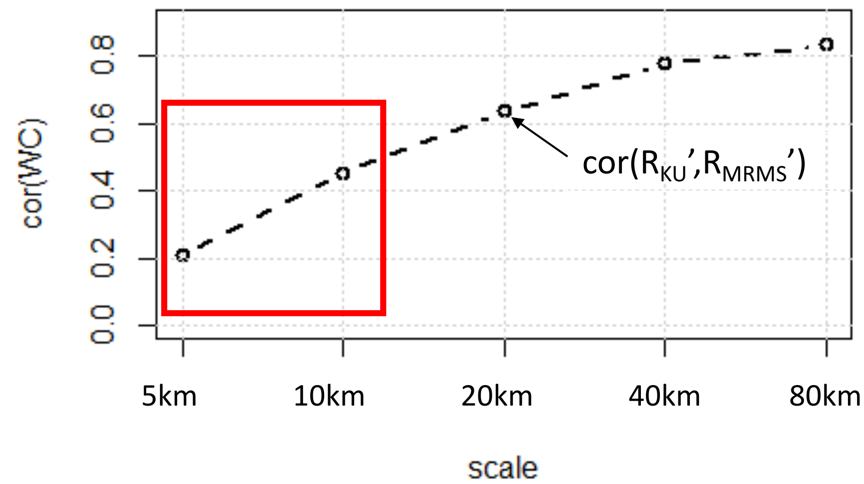

Spatial variations of KuPR and MRMS fields: low correlation at scales finer than 20km.

At fine scales location errors affect retrievals (+ training database?)

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Take away messages

1) GPM era (GMI, GPROF-2017) vs TRMM era (TMI, GPROF-2010):

- Over oceans: ER is improved from 20~40km to 10~20km. Both GPROF-2010 and GPROF-2017 are smooth estimates.
- Over land: GPROF-2017 and GPROF-2010 have similar ER: 20~80km with large variability depending on geographical areas. GPROF-2017 (Bayesian retrieval) is smoother than GPROF-2010, leading to lower MSE.
- GPROF-2017 performs as well in tropical and extra-tropical areas, except for southern ocean (because of sea ice?).

2) Lower ER over land is surprising considering that the HF channels (>80GHz), which provide most of the information over land, have the best resolution.

=> Instrumental resolution does not seem to be the main driver of the ER.

Information content of different channels

Lower ER over land is surprising considering that the HF channels (>80GHz), which provide most of the information over land, have the best resolution.

=> Instrumental resolution does not seem to be the main driver of the ER.

Diagnostics => New Perspectives

Objective: achieve over land the same ER as over oceans.

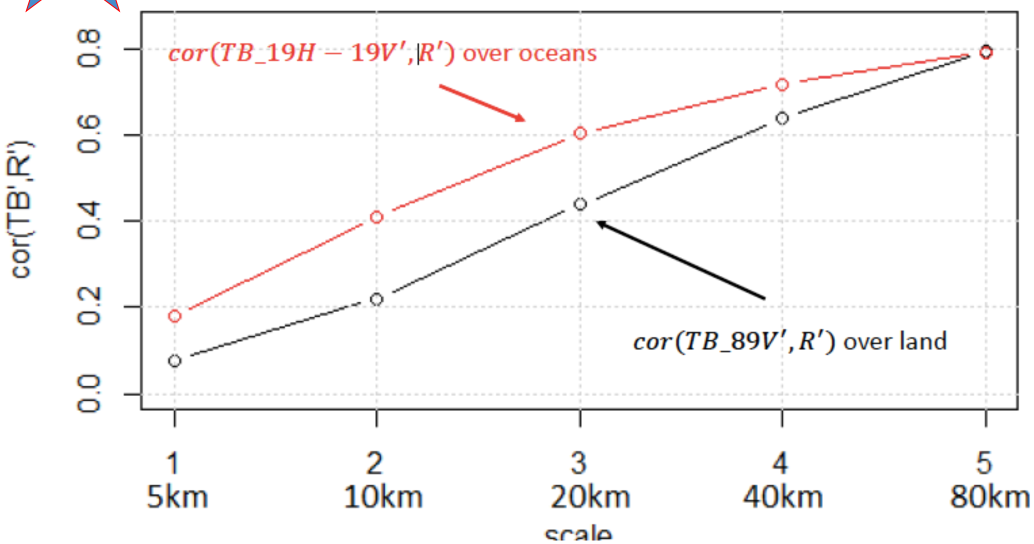
1) Retrieval over land relies mostly on HF channels. HF channels are sensitive to clouds' ice content:

- QU: **How well do we retrieve cloud ice over land with GMI?** => *compare TB 89GHz to DPR reflectivity above the bright band.*
- QU: **Down to which scale can cloud ice content predict surface precipitation?** => *compare DPR reflectivity above the bright band to surface precipitation.*

- QU: How much does **geometry –spatial/temporal mismatch between clouds and surface precipitation, parallax shift …** – limit the retrieval of fine scale patterns?

2) QU: **How to better exploit the LF emission signal over land?**

Information Content of Various GMI channels



The coarse-scale spatial variations of TB_19H-19V' are linearly correlated with spatial variations of R' over oceans

The coarse-scale spatial variations of TB_89V are linearly correlated with the spatial variations of R' over land, but the Correlation decreases with scale

Despite their coarser resolution, the LF channels of GMI (19H and V), which are sensitive to raindrop emission signal, contain more information about surface fine-scale precipitation variability than the better resolved HF channels (89 V, H) over land

Global multiscale evaluation of satellite passive microwave retrieval of precipitation during the TRMM and GPM eras: effective resolution and regional diagnostics for future algorithm development

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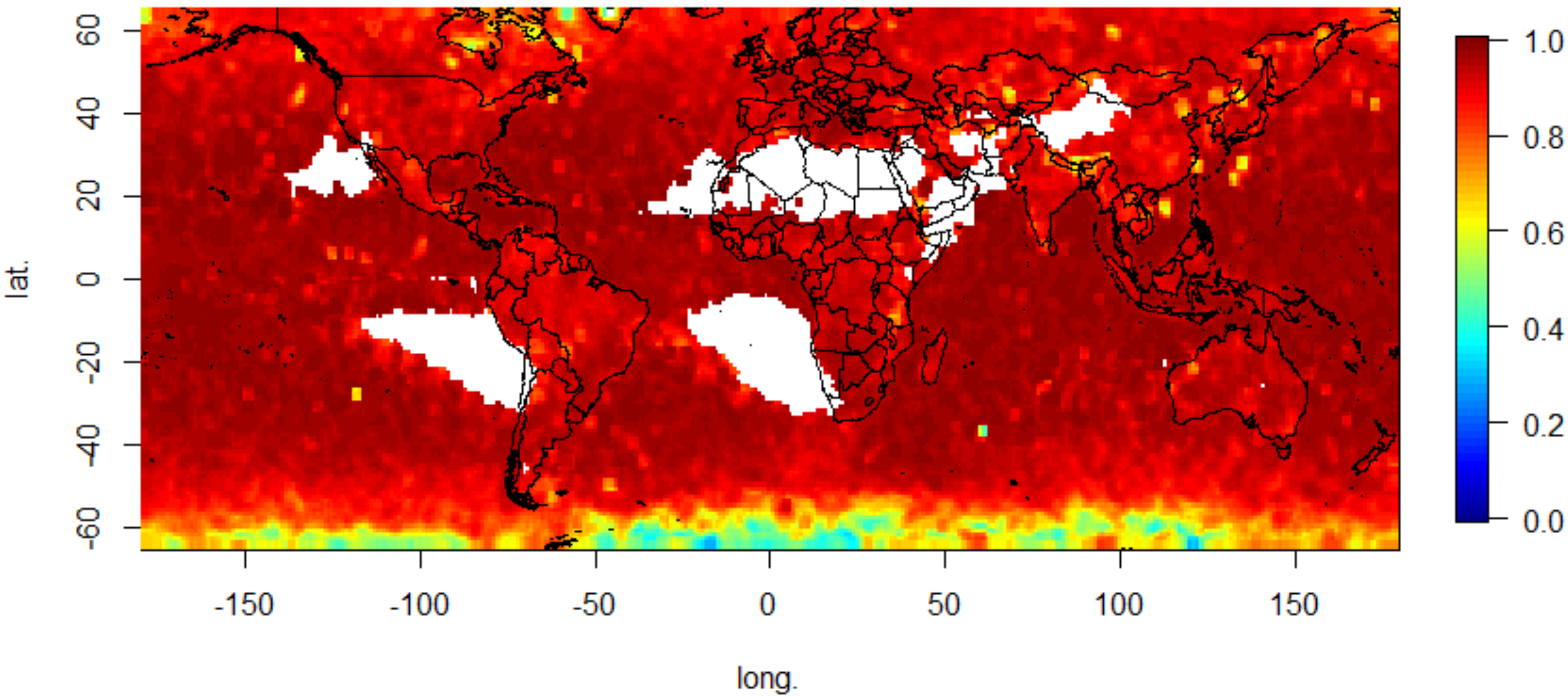
Published Online: 25 September 2017

Global evaluation of GPROF-2017

- Correlation of the LP components (scales>80km): GPROF-GMI vs KuPR



For more details pls see our paper in J. Hydrometeorology

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WAVELET ANALYSIS FOR GEOPHYSICAL APPLICATIONS

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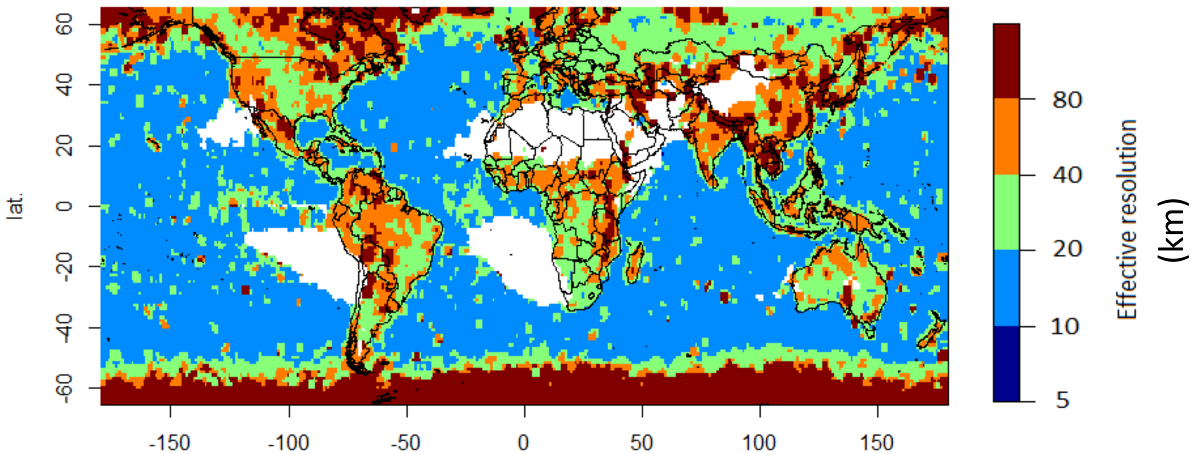
University of Minnesota at Minneapolis-St. Paul

Abstract. Wavelet transforms originated in geophysics in the early 1980s for the analysis of seismic signals. Since then, significant mathematical advances in wavelet theory have enabled a suite of applications in diverse fields. In geophysics the power of wavelets for analysis of nonstationary processes that contain multiscale features, detection of singularities, analysis of transient phenomena, fractal and multifractal processes, and signal compression is now being exploited for the study of several processes including space-time precipitation, remotely sensed hydrologic fluxes, atmospheric turbulence, canopy cover, land surface topography, seafloor bathymetry, and ocean wind waves. It is anticipated that in the near future, significant further advances in understanding and modeling geophysical processes will result from the use of wavelet analysis. In this paper we review the basic properties of wavelets that make them such an attractive and powerful tool for geophysical applications. We discuss continuous, discrete, orthogonal wavelets and wavelet packets and present applications to geophysical processes.

Global evaluation of GPROF-2017



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-ER>80km: Himalayas (mountains), South-East Asia, Coasts above 50° N.
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-20~40km ER over land even in regions where deep convection is not dominant (e.g. Europe, Siberia …)

>> Looking at the maps at all scales of the var(MW'), Var(KuPR'), correlation plots provides more insight