Characterizing fAPAR variability and complexity on multiple scales

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- What is fAPAR? Why measuring it?
- Measures of complexity – very short introduction
- Results: H_S and MPR-C_{JS}
- Decomposition according to timescales
- Conclusions

fAPAR = fraction of Absorbed Photosynthetic Active Radiation

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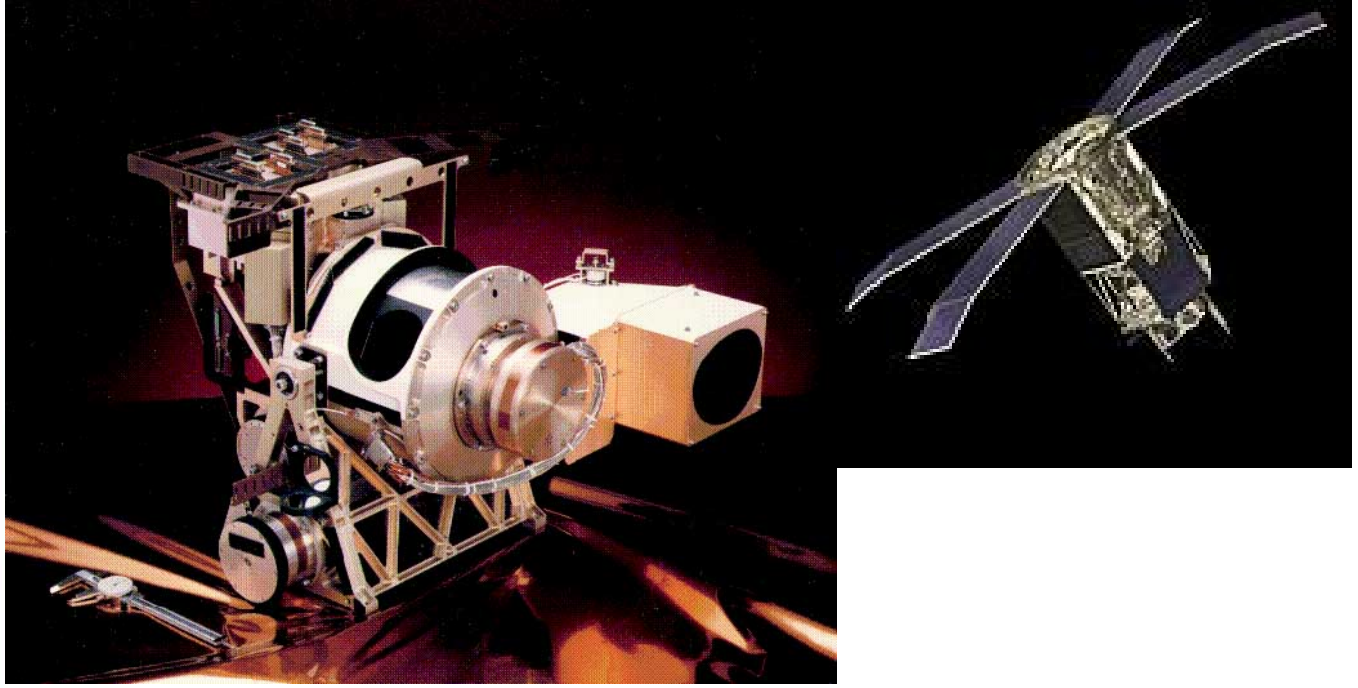
- also called fPAR
- range [0,1]
- ”absorbed” means: biologically uptaken
- index directly related to primary productivity
- requires at least three spectral bands: blue, red, near-infrared
- routinely available from satellites: MODIS, MERIS, …
- here, we use SeaWifs data
- 1998-2005, 10-day composites, 0.5 x 0.5° spatial resolution
- gridded temperature data: CRU-PIK
- gridded precipitation: GPCC



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SeaWifs: Sea-viewing Wide field-of-view sensor

- on board *OrbitalViewer-2*
- ”land-viewing” as well!
- part of NASA’s *Earth Science Enterprise*
- launching date Aug. 1st, 1997
- 705 km altitude, equatorial noon sun-synchronous orbit
- revisit time 1 day, resolution 1.1 km
- 8 bands, 402 – 885 nm

Motivation and Approach

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- **Some relevant questions**

- What spatiotemporal patterns are found in fAPAR data?
- To what extent are these patterns explained by temperature and precipitation?
- Do the patterns lead to a (new) classification of the biosphere?
- Are the spatial patterns different at varying time scales?

- **Our approach**

- Quantify the *complexity* of pixel time series at each time scale
- Relate to climate, vegetation, land-use, ...
- Decompose fAPAR time series into time scales (with e.g. FFT, SSA or EMD)
- **Time Scales**: short (< 4.5 months), semiannual, annual, long

fAPAR-T-P connection for temporal averages

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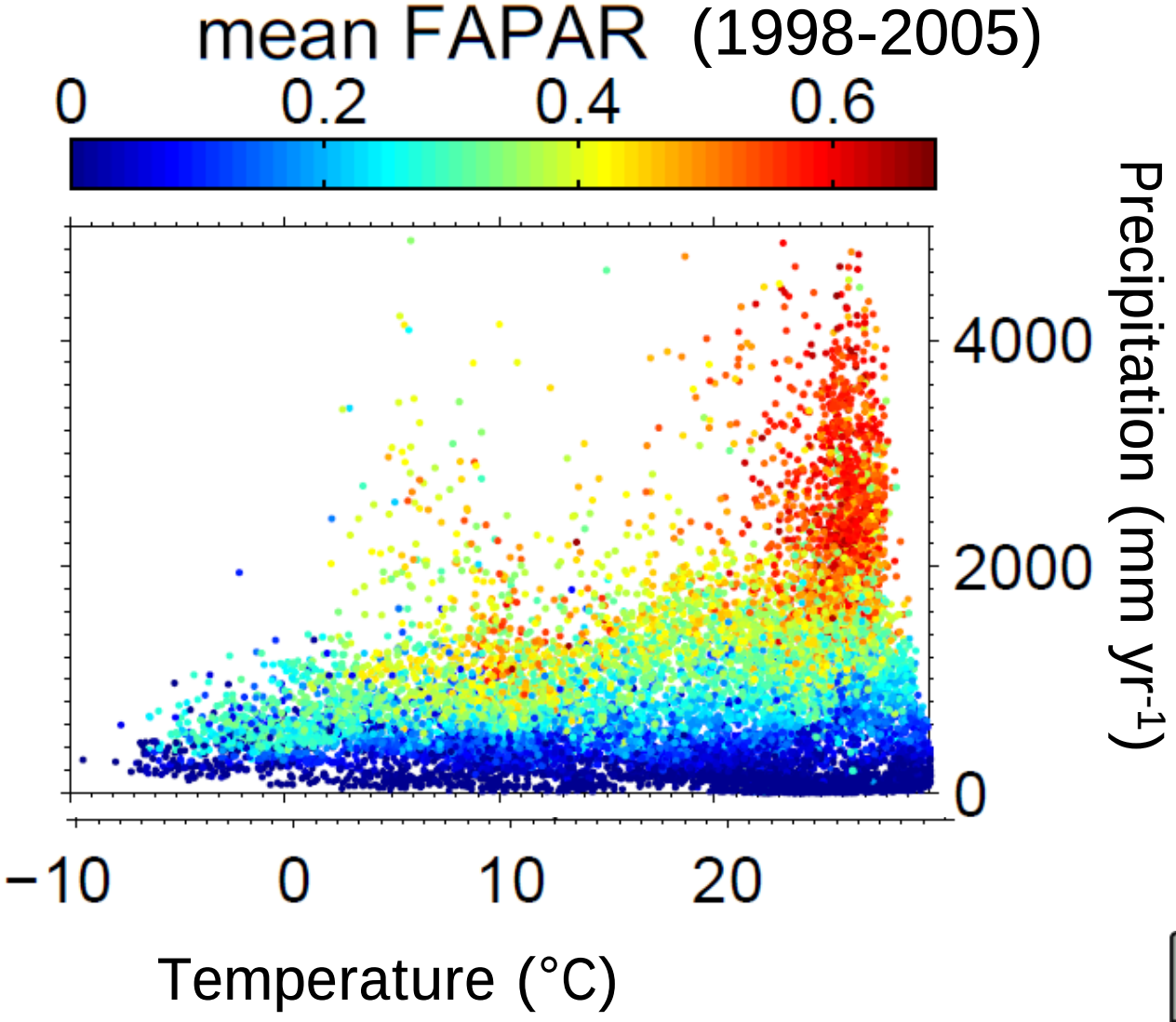

Information and Complexity of Time Series

1. **Information**

   (first order in randomness)

   Zero for constants, max for pure noise

   Here: *Time-ordered* **Shannon entropy**

2. **Complexity**

   (second order in randomness)

   Zero for constants, zero for pure noise

   Max for structured data

   Here: **Jensen-Shannon MPR Complexity**:

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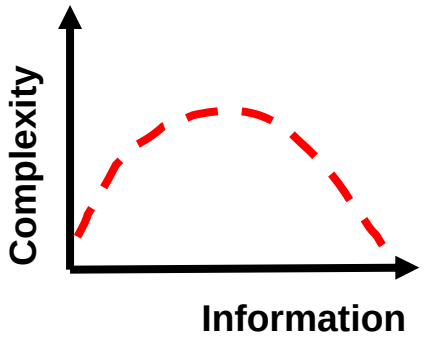
$$H_S = S / S_{\max}$$

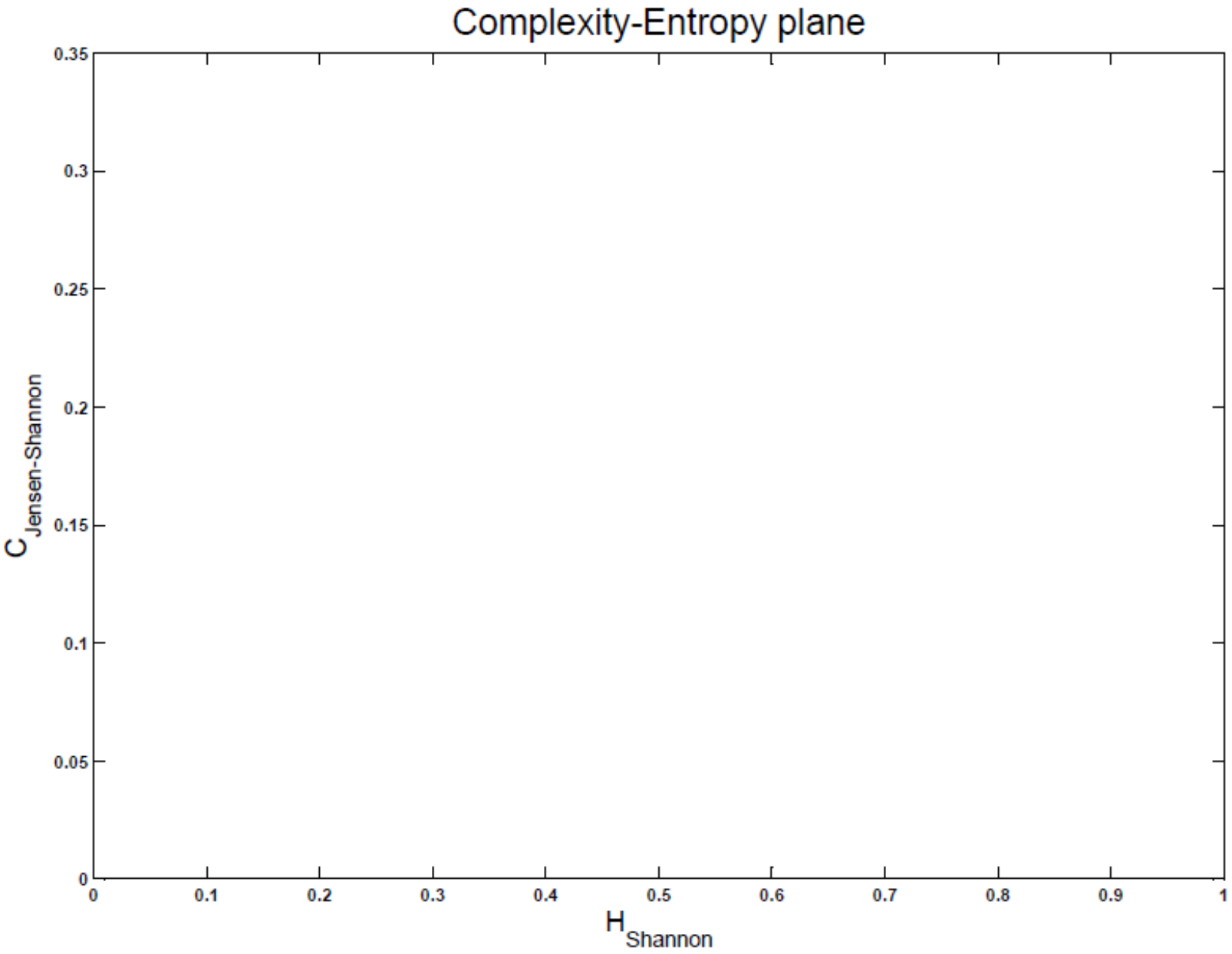
$$C_{JS} = S[P] Q_{JS}[P, P_e] / S_{\max}$$

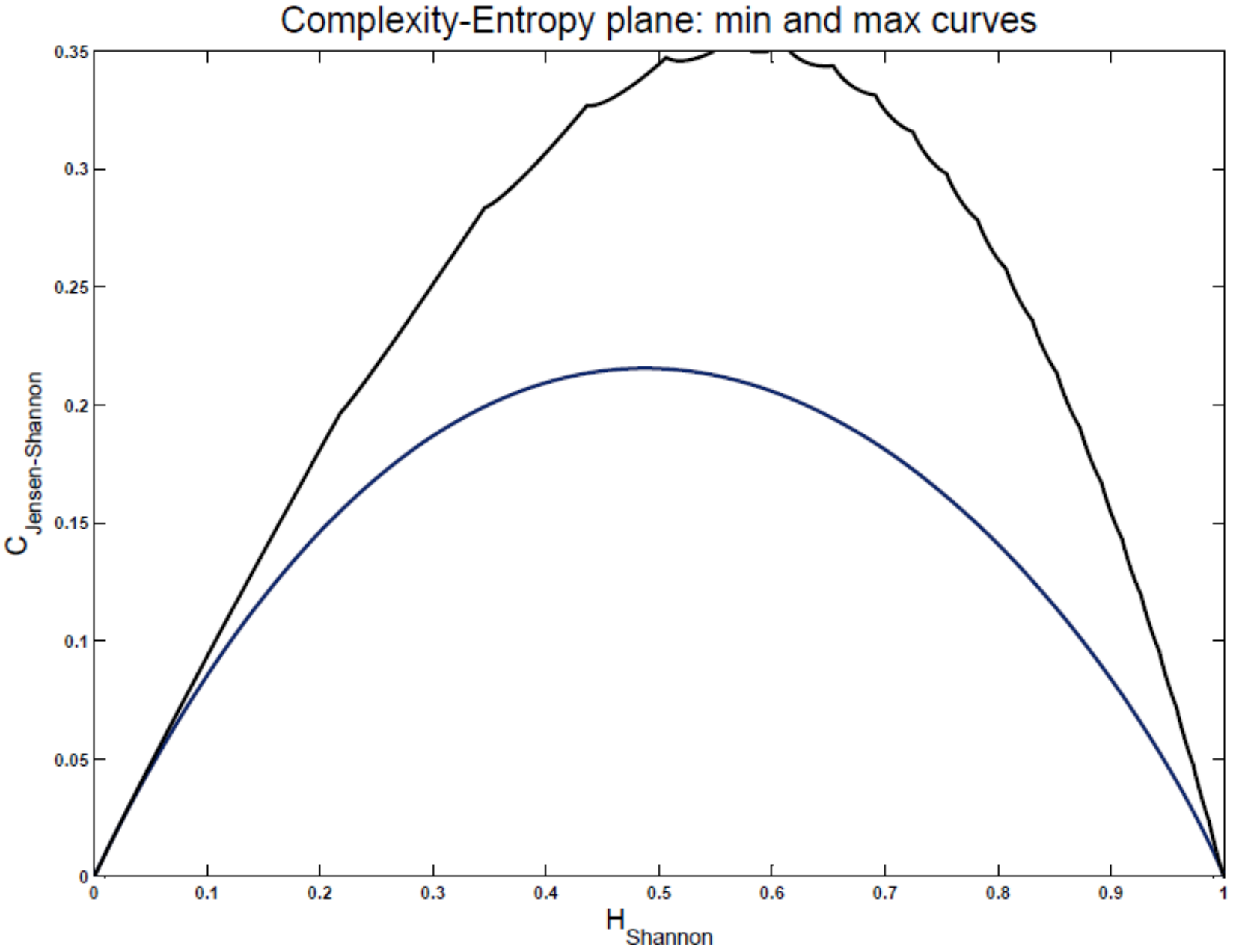
$$Q_{JS} = Q_0 \{ S[(P + P_e)/2] - S[P]/2 - S[P_e]/2 \}$$

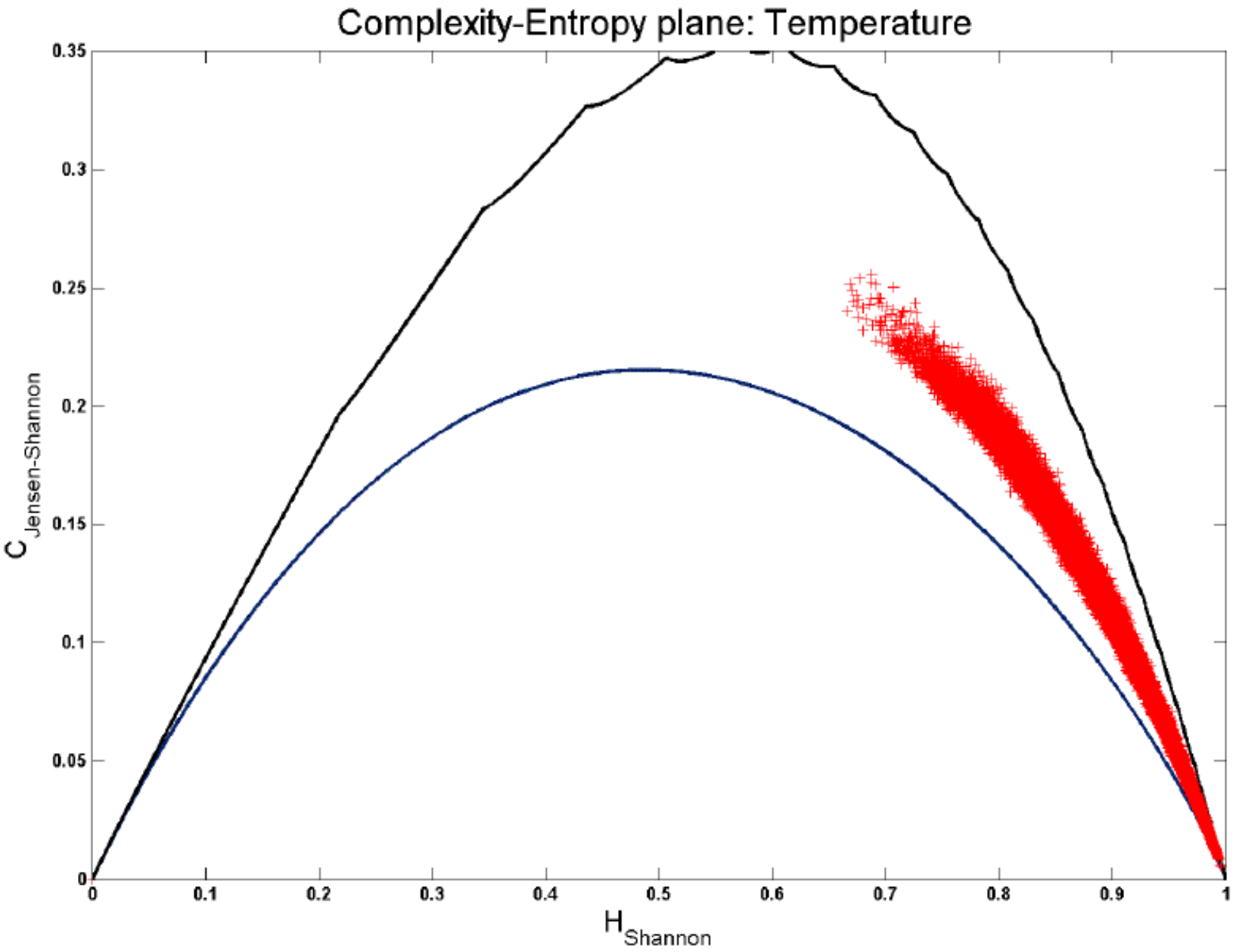
P_e is a reference distribution

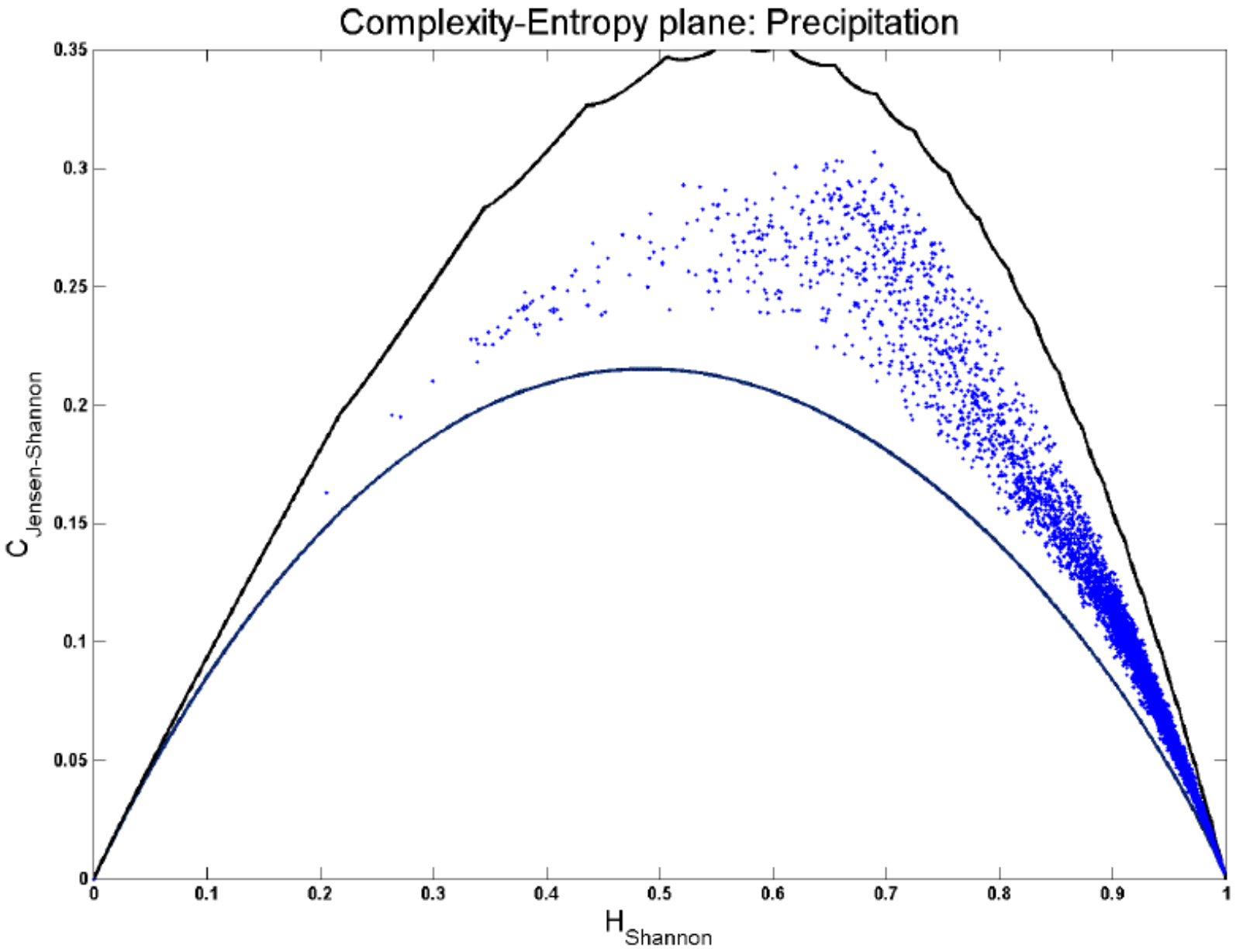
P is estimated from the TS
using ordinal patterns involving
an embedding dimension D (=4 in this talk)

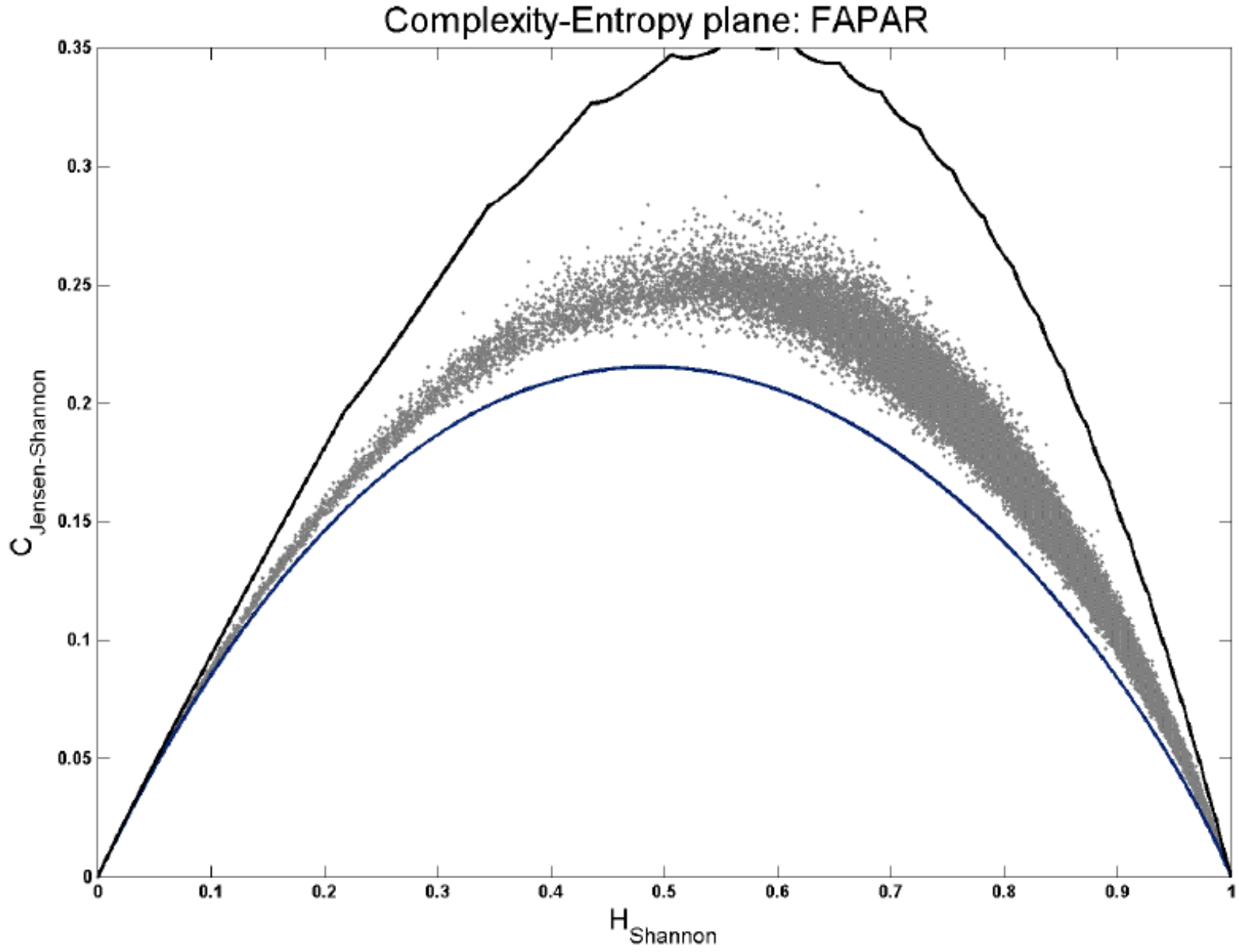


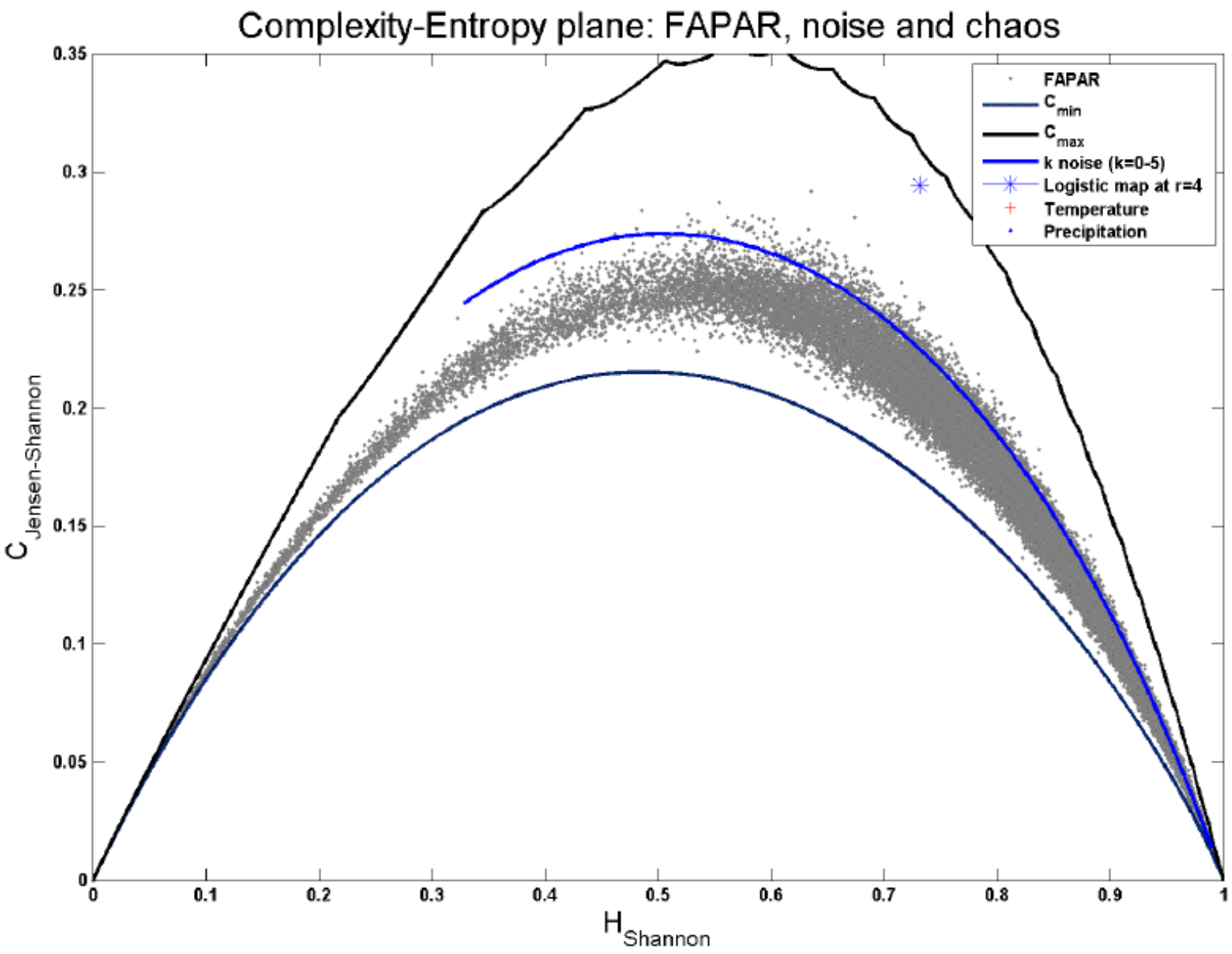

Complexity-Entropy plane
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
C Jensen-Shannon
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
H Shannon

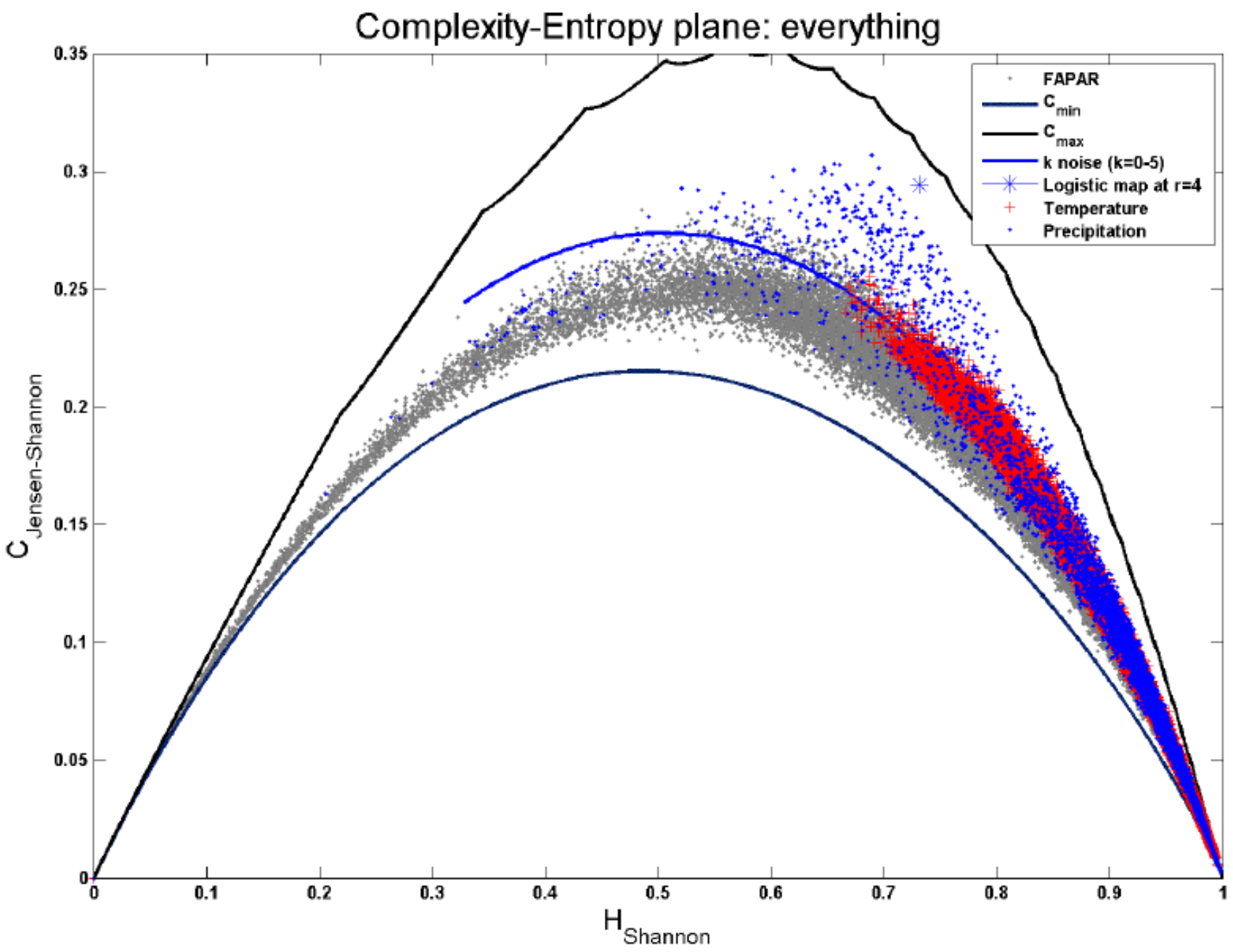

Complexity-Entropy plane: min and max curves
C Jensen-Shannon
H Shannon
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

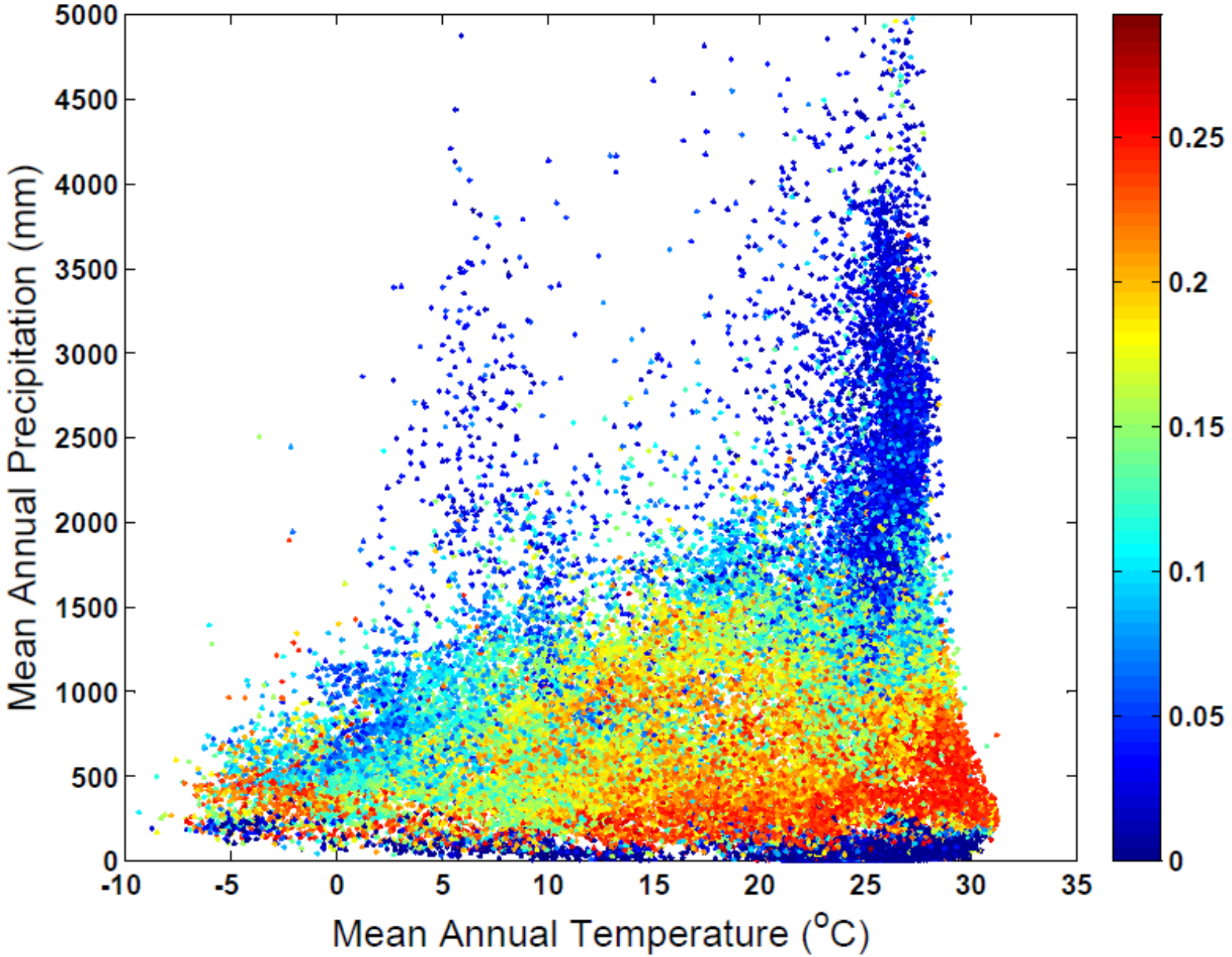

Complexity-Entropy plane: Temperature
C Jensen-Shannon
H Shannon
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Complexity-Entropy plane: Precipitation
C Jensen-Shannon
H Shannon
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

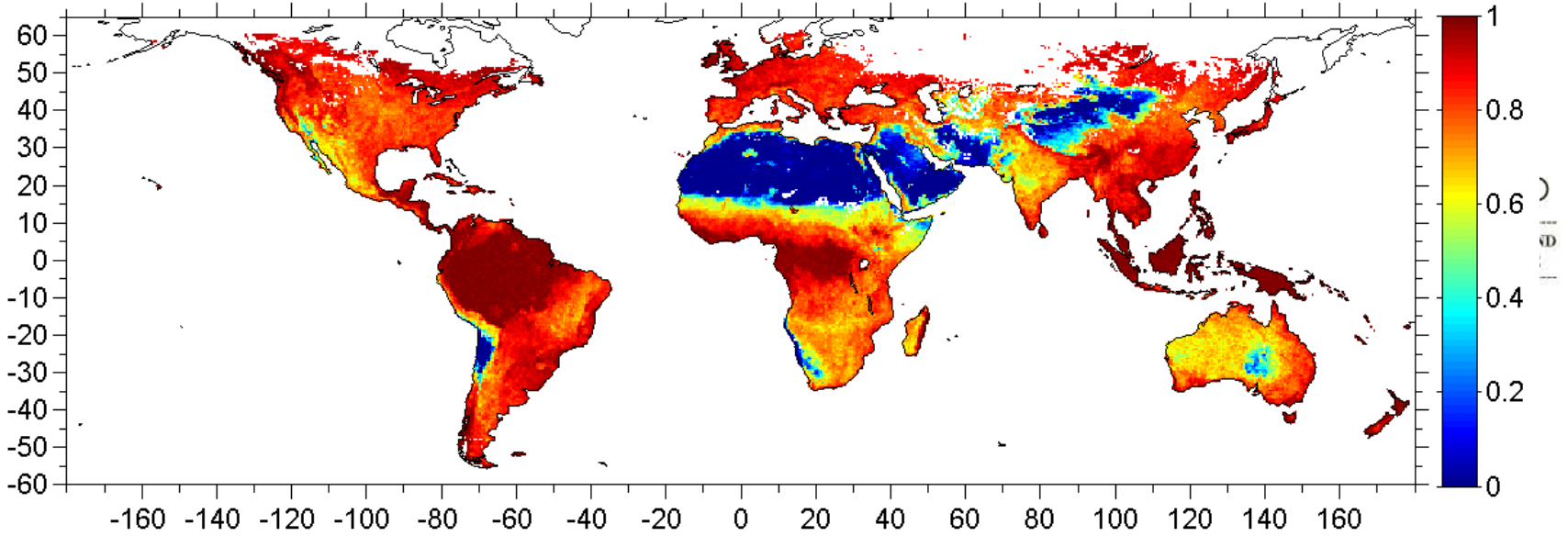

Complexity-Entropy plane: FAPAR
C Jensen-Shannon
H Shannon
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1


Complexity-Entropy plane: FAPAR, noise and chaos
FAPAR
C min
C max
k noise (k=0-5)
Logistic map at r=4
Temperature
Precipitation
C Jensen-Shannon
H Shannon
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

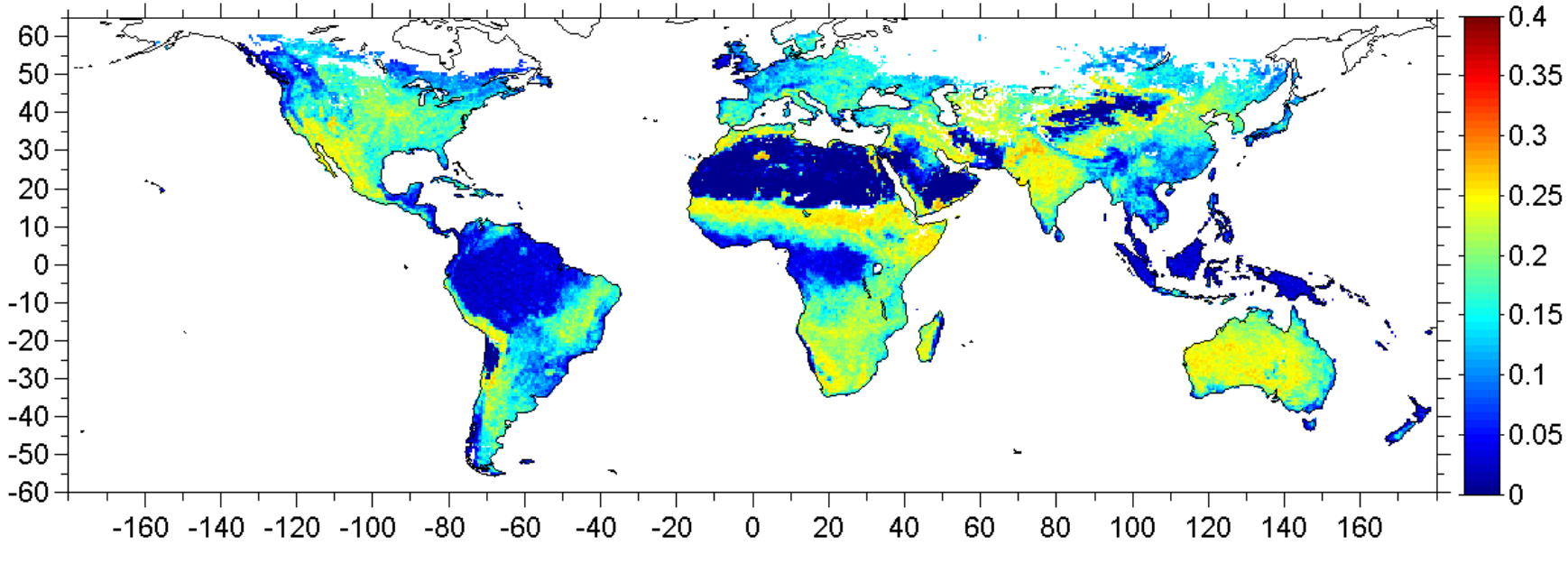

Complexity-Entropy plane: everything
FAPAR
C min
C max
k noise (k=0-5)
Logistic map at r=4
Temperature
Precipitation
C Jensen-Shannon
H Shannon
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

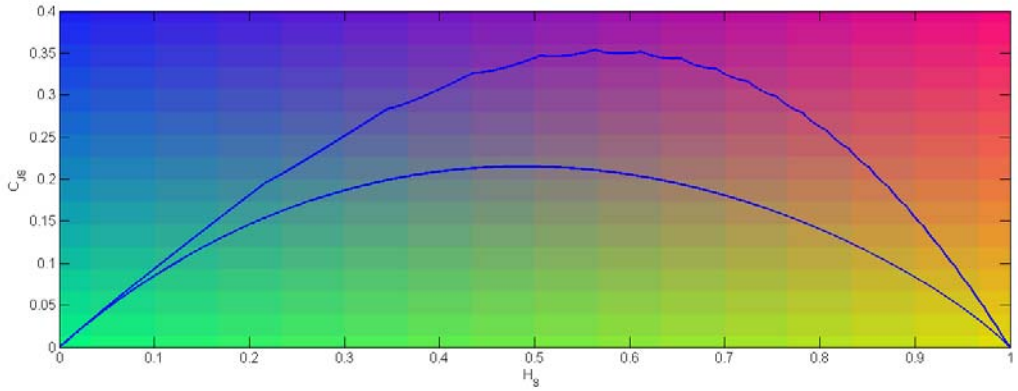

MPR Complexity values of FAPAR in the climate space
Mean Annual Precipitation (mm)
5000
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-10
-5
0
5
10
15
20
25
30
35
Mean Annual Temperature (°C)
0.25
0.2
0.15
0.1
0.05
0

Shannon Entropy of FAPAR



Complexity of FAPAR





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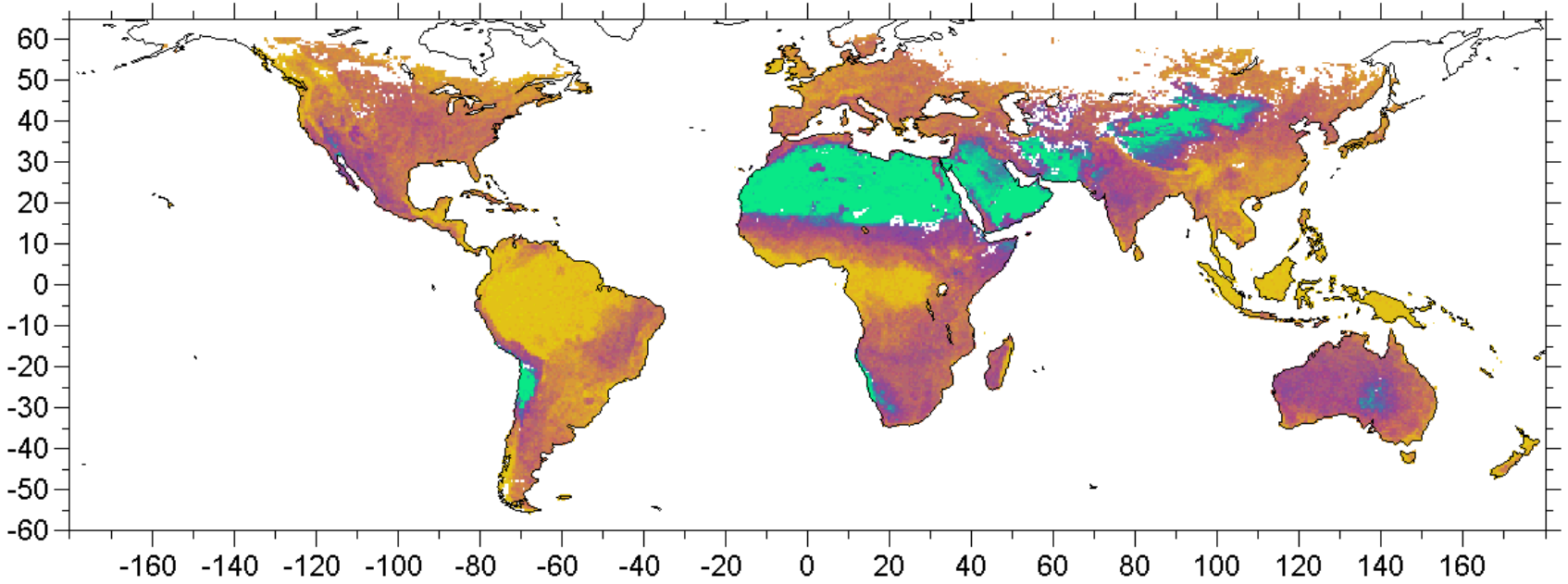
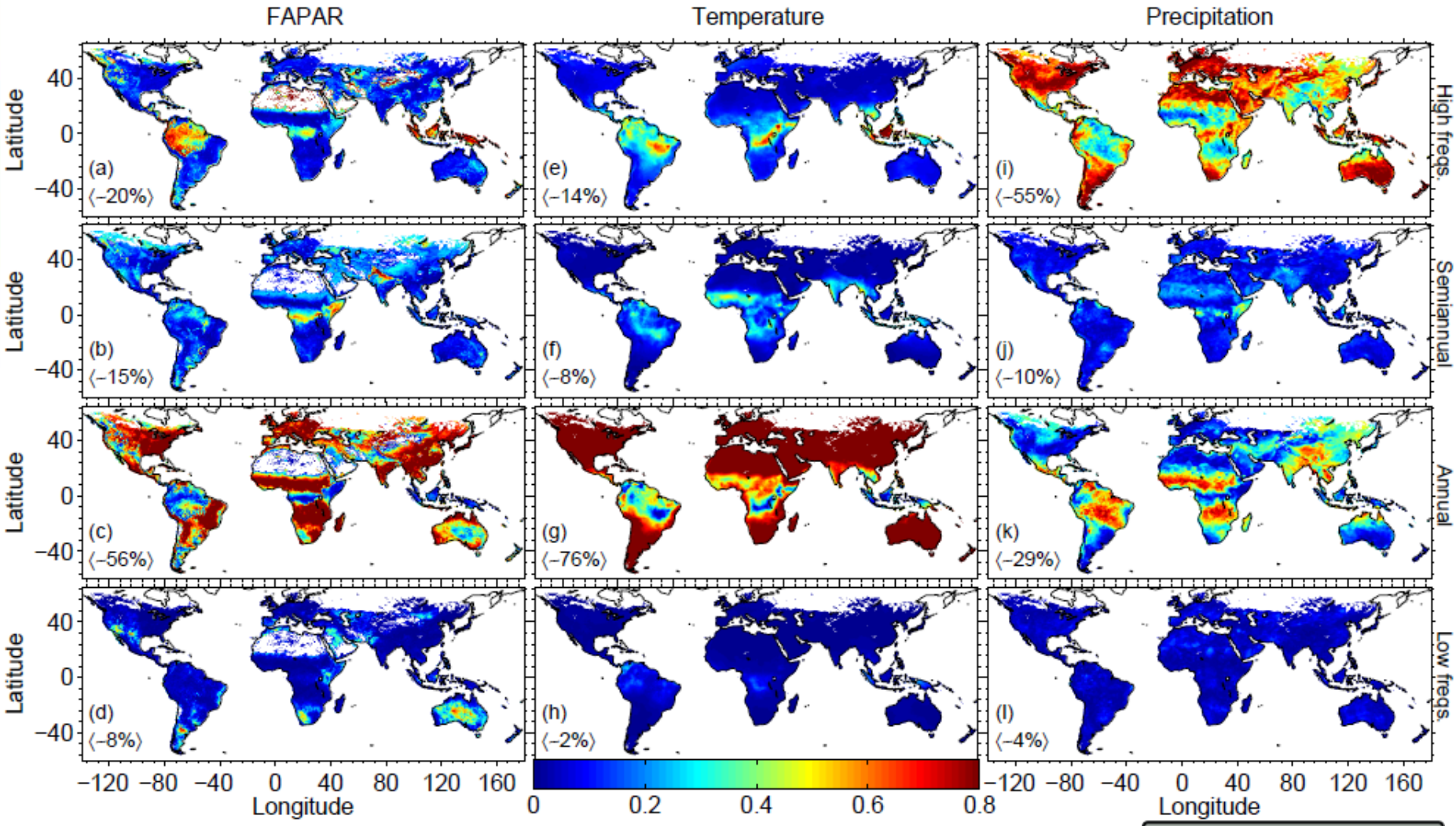
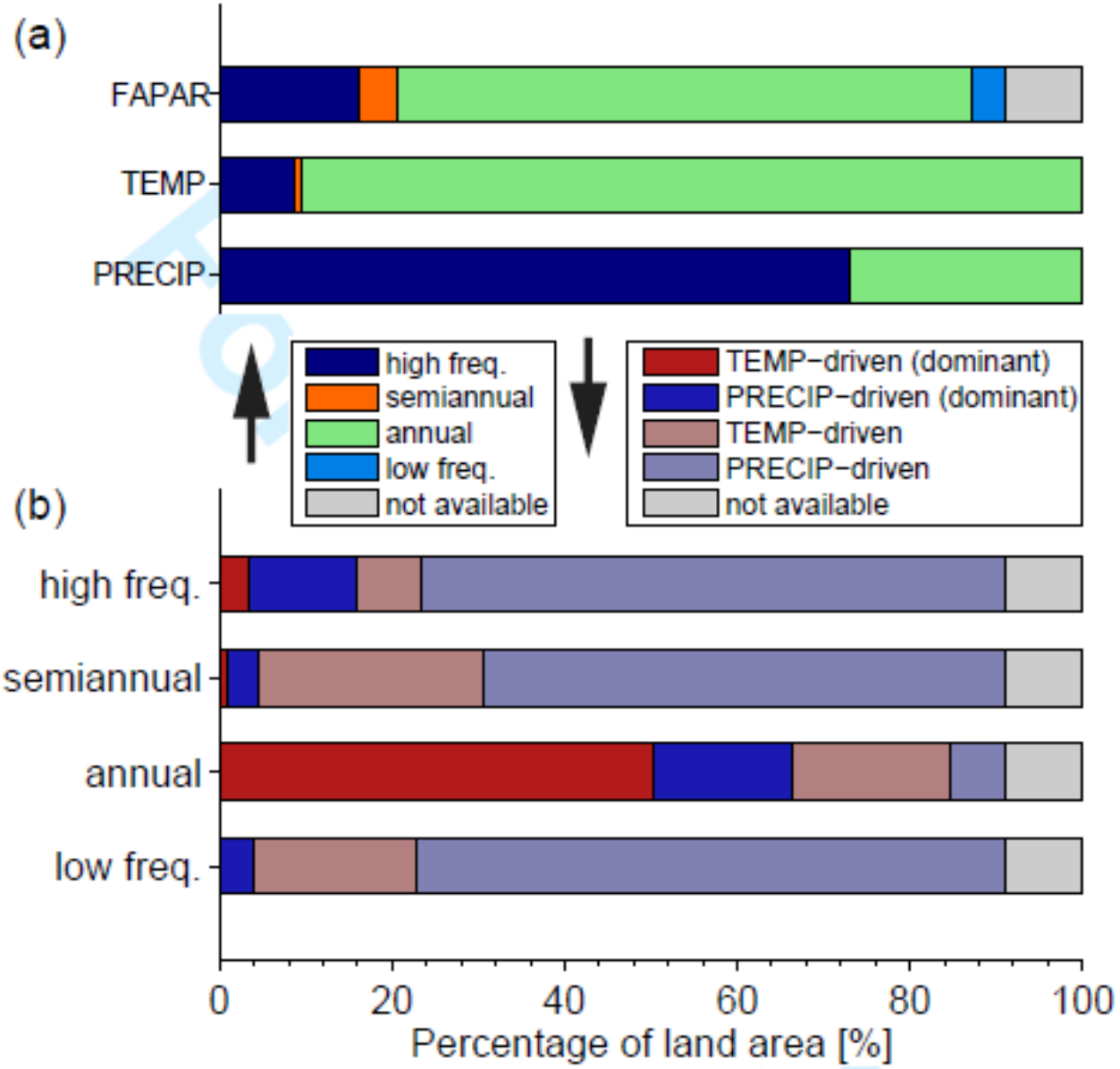
Entropy and complexity for FAPAR



Decomposition into timescales (FFT)



Dominant time scales and land cover



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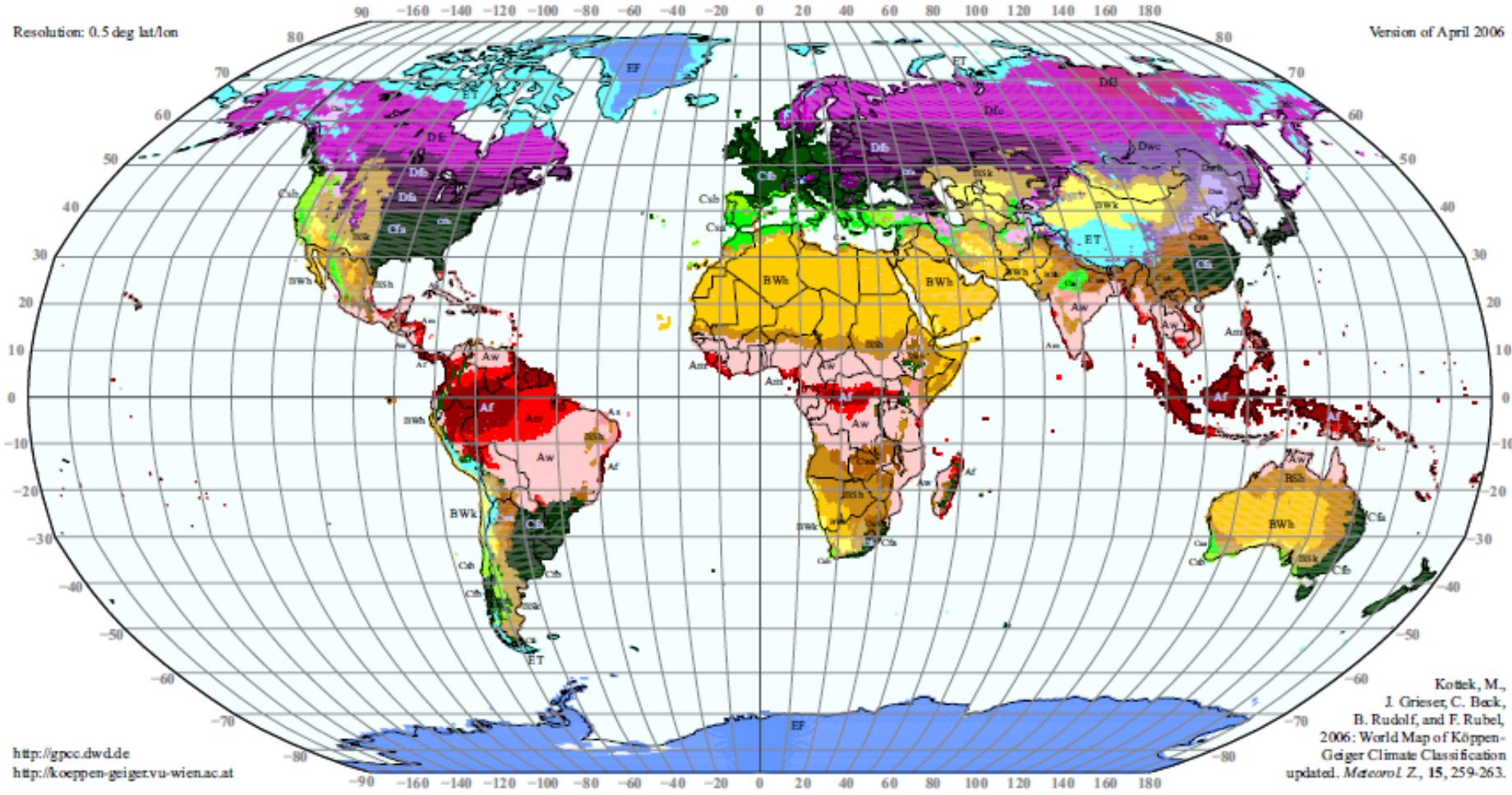
World Map of Köppen–Geiger Climate Classification

updated with CRU TS 2.1 temperature and VASClimO v1.1 precipitation data 1951 to 2000

Main climates	Precipitation	Temperature	
A: equatorial	W: desert	h: hot arid	F: polar frost
B: arid	S: steppe	k: cold arid	T: polar tundra
C: warm temperate	f: fully humid	a: hot summer	
D: snow	s: summer dry	b: warm summer	
E: polar	w: winter dry	c: cool summer	
	m: monsoonal	d: extremely continental	

Af Am As Aw BWk BWh BSk BSh Cfa Cfb Cfc Csa Csb Csc Cwa

Cwb Cwc Dfa Dfb Dfc Dfd Dsa Dsb Dsc Dsd Dwa Dwb Dwc Dwd EF ET



Does the fAPAR-T-P decomposition resemble the Köppen-Geiger classification?

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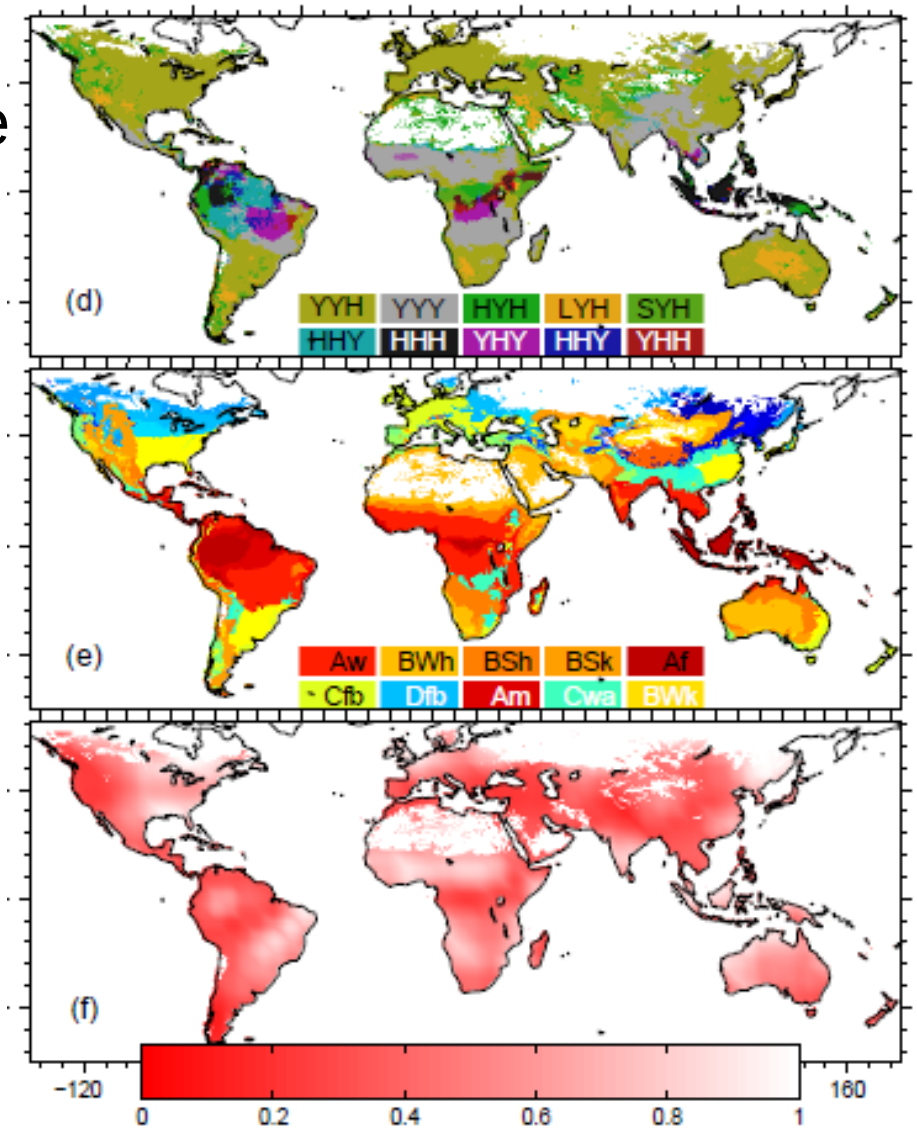
Dominant FFT scale
(fAPAR-T-P)

Köppen-Geiger

Similarity index
(0 – dissimilar, 1-similar)



Summary and Conclusions

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> fAPAR not only driven by climate
> Complexity of fAPAR reveals spatially varying relations to climate (+ many surprises)
> T: high information content/not very complex,
P: medium to high information content/ complexity
fAPAR: could be everything
> k noise and deterministic chaos are no good process candidates (on time scales 10 days – one month)

> timescale decomposition successful:
  - plenty of detailed information
  - very different patterns on the individual time scales
  - fAPAR-P-T connections are scale-dependent (not shown)

> analysis opens up for an innovative classification of biomes
> Additional drivers (land-use change, fires, ...) needed