Reduced-Dimensional Retrievals of Precipitation from the TRMM Microwave Imager: Physical Insight and Information Content

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Introduction

- TRMM:

  Launched in Nov 1997

  Latitude range: 40S ~ 40N

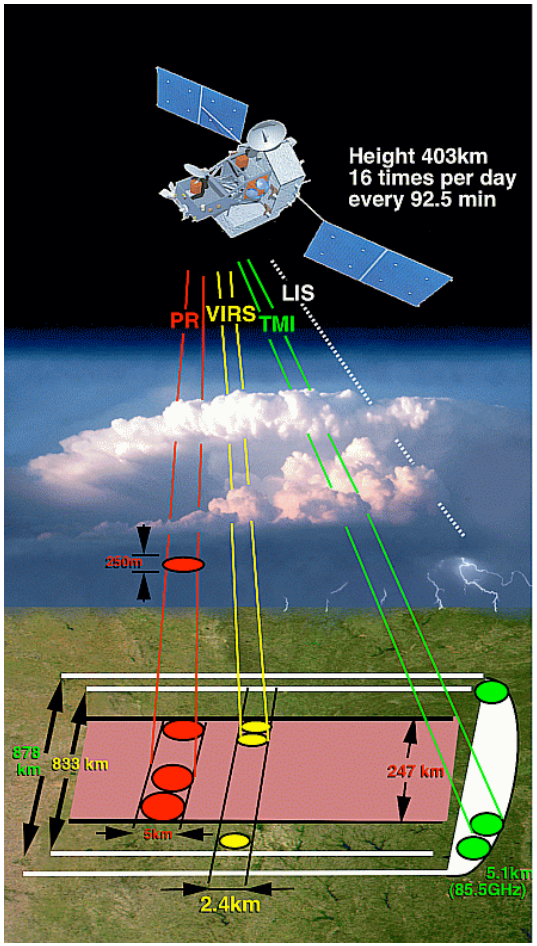
  Precipitation Radar (PR): 5km/247km

  Microwave Imager (TMI):

  15km/833km (resolution of 19GHz)

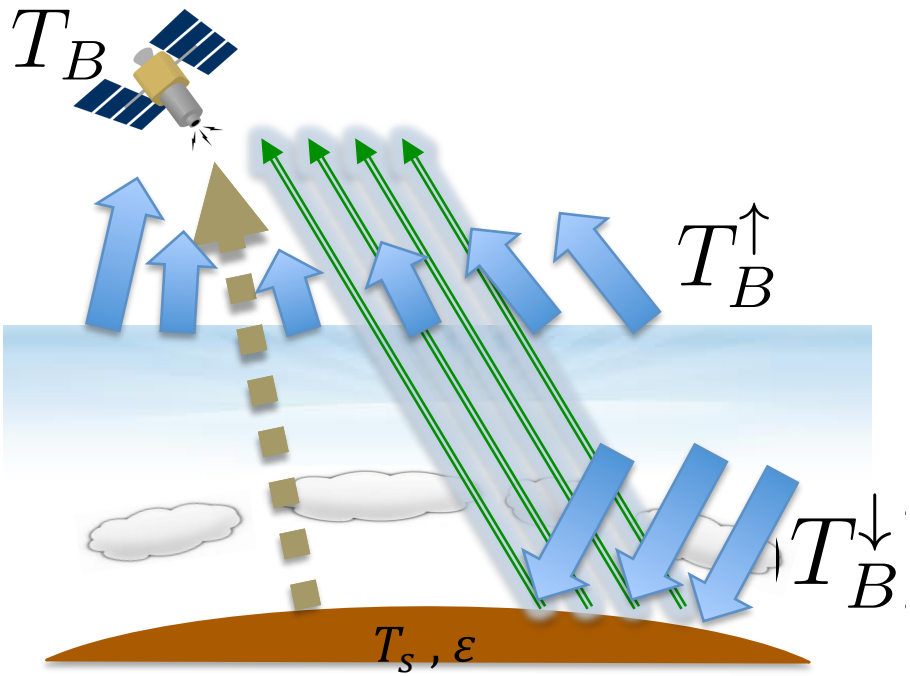
  Microwave channels:

  10, 19, 37, 85.5GHz (vertical and horizontal), and 21GHz vertical



- Microwave Channels (features)
- Bayesian estimation methods (Petty 2012)
- Three most important physical signatures for TRMM rain-rate retrieval
- How important is each component?

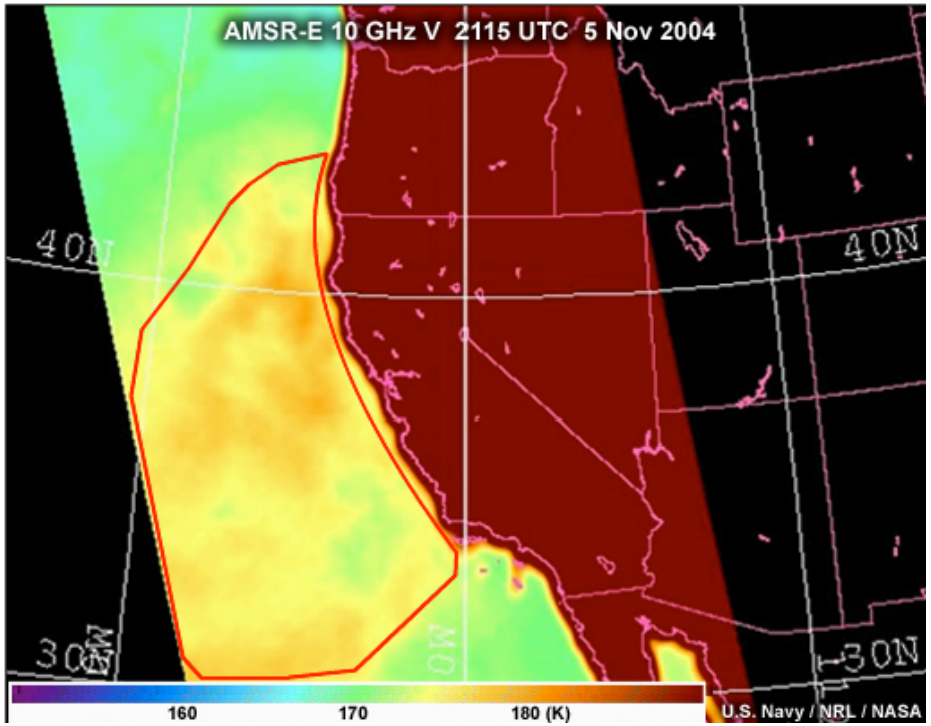
Passive Microwave Remote Sensing



$$T_B = T_B^{\uparrow} + \tau(0,\infty)[\varepsilon_s T_s + (1-\varepsilon_s)T_B^{\downarrow}]$$

Background: Ocean and Land

Ocean background: cold + strong polarization



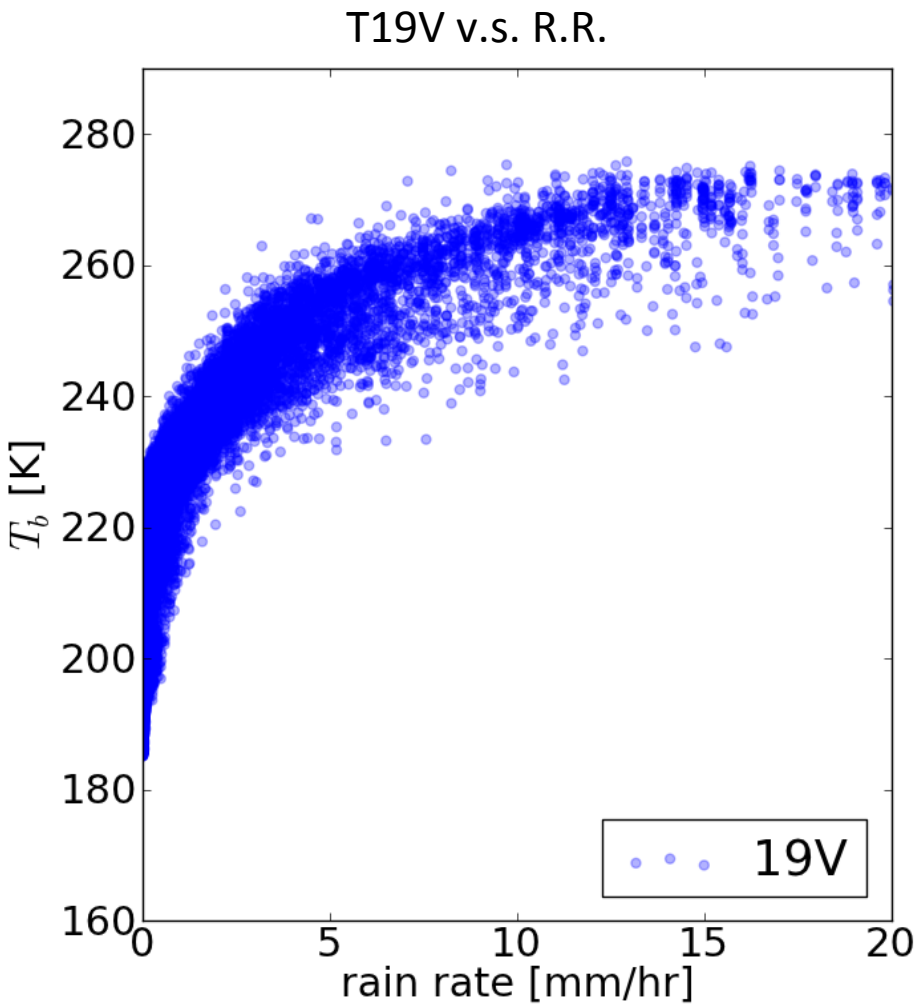
- Polarization: Vertical (V) and Horizontal (H) for 10, 19, 37, and 85.5GHz
- Over the ocean, emissivity:

$$\varepsilon_H < \varepsilon_V < 1 \qquad \text{strong polarization}$$

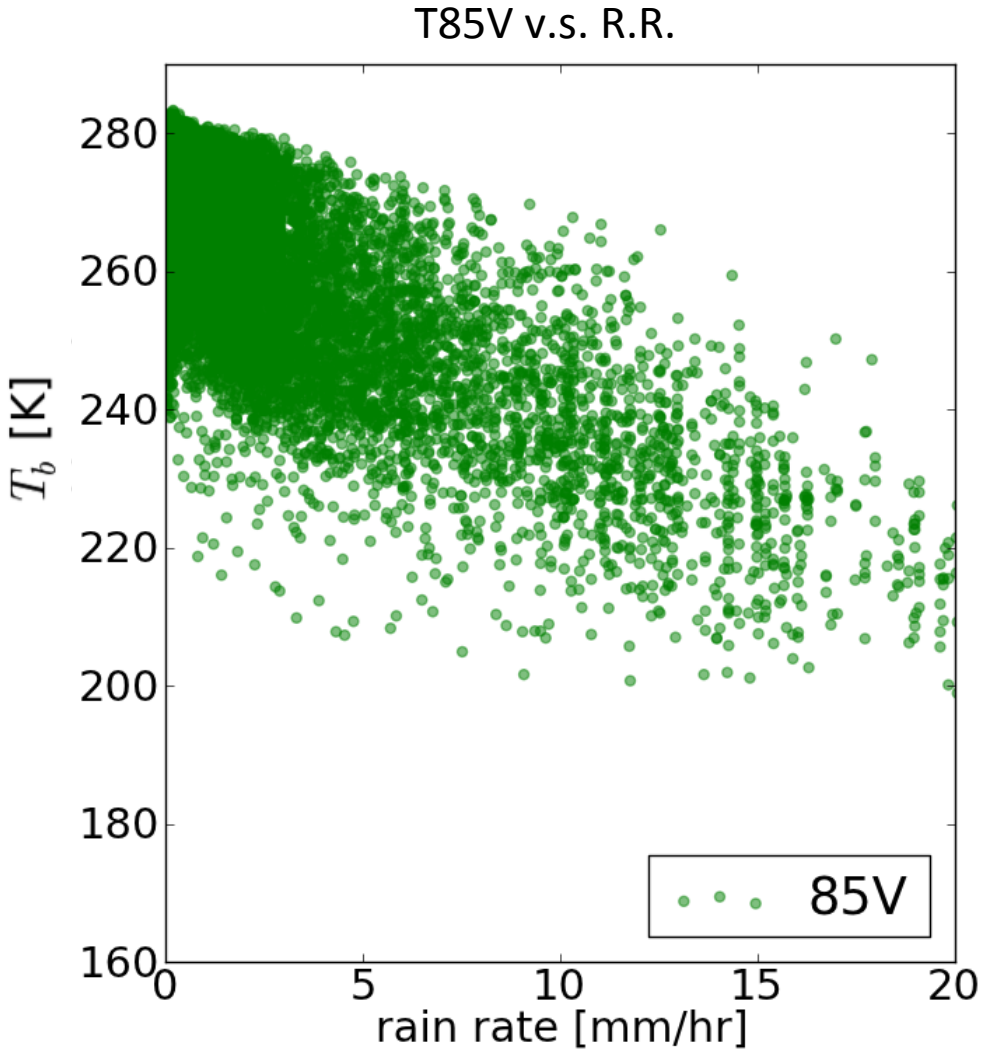
- Over the land, emissivity:

$$\varepsilon_H \approx \varepsilon_V \approx 1 \qquad \text{weak polarization}$$

Frequency and rain rate



Frequency and rain rate



Bayesian Retrievals

- Bayes' theorem (Bayes and Price, 1763)

$$P(A|B) \propto P(A) \cdot P(B|A)$$

- Bayesian Monte Carlo (MBC):
  - Large data base for PDF collect candidate solutions(L'Ecuyer and Stephens, 2002)
- Bayesian with Cloud resolving models:
  - Matching Tb (Kummerow 2006)

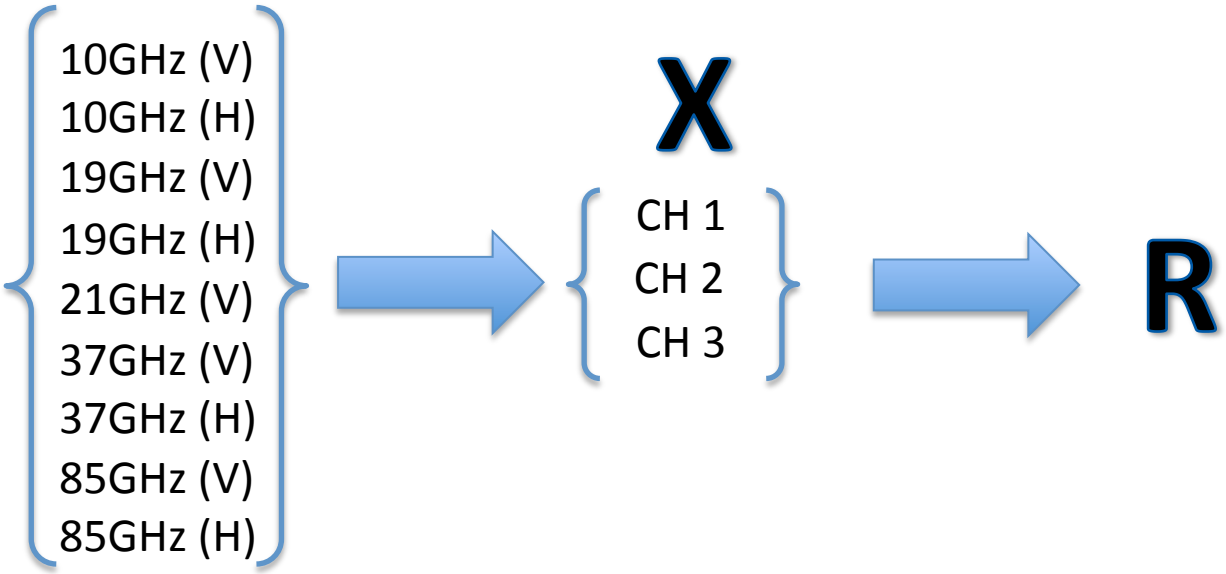
UW Bayesian Algorithm

- Uses TMI-PR matchup data, no cloud resolving models
- No conceptual distinguish between ocean and land
- No ‘screening’
- Pre-averages a priori database into 5D lookup table
- No weighting for candidate solutions
- Produces posterior distribution and averaged rain rate to replace ‘error bar’

(Petty and Li, 2013a,b)

Dimensional Reduction

- Noise reduction
- Sample density maintaining
- Memory requirement reduction

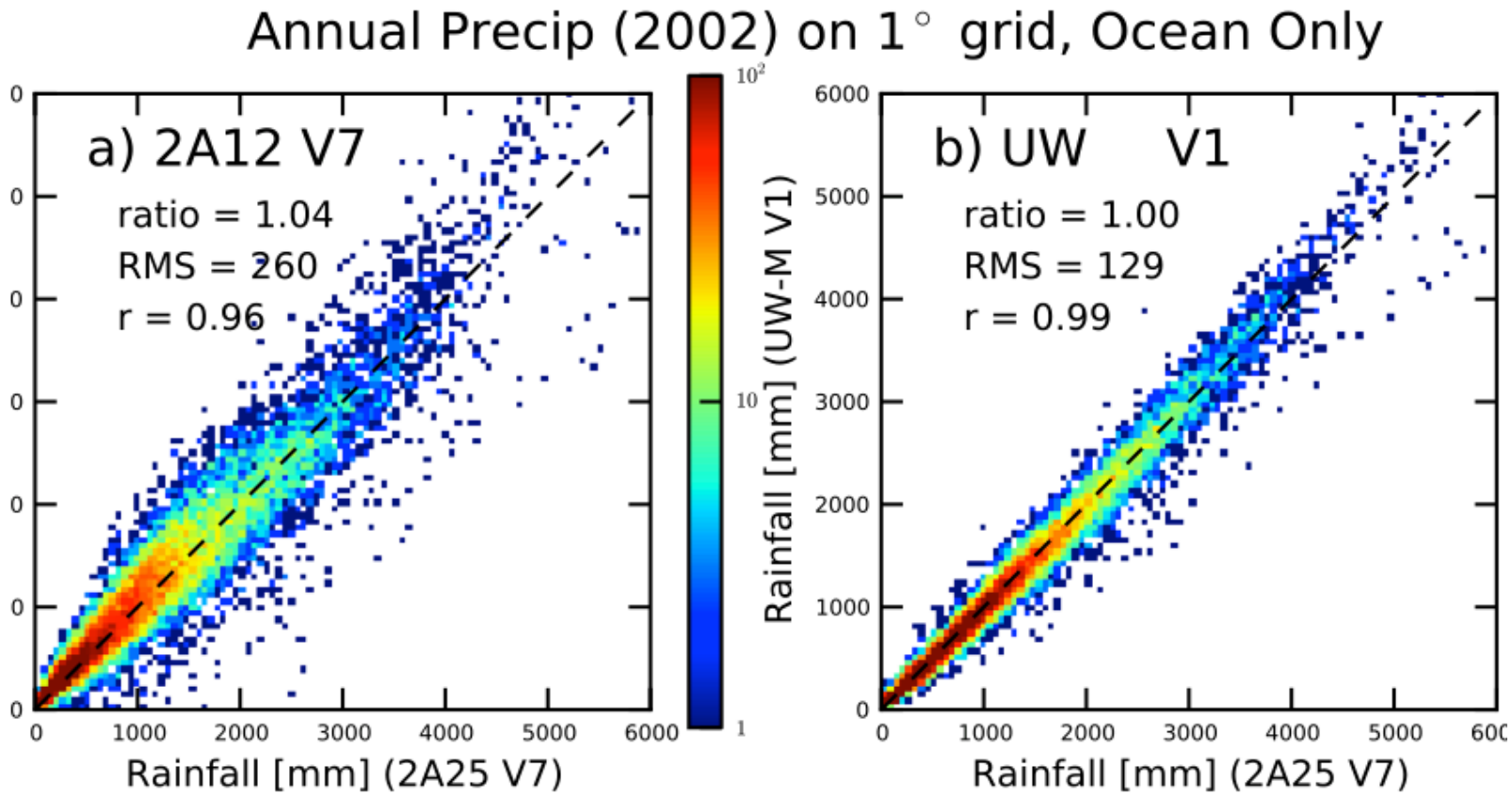


- Principle Component Analysis (Petty 2012)

Step 1: Normalize the geophysical noise among non-rain samples

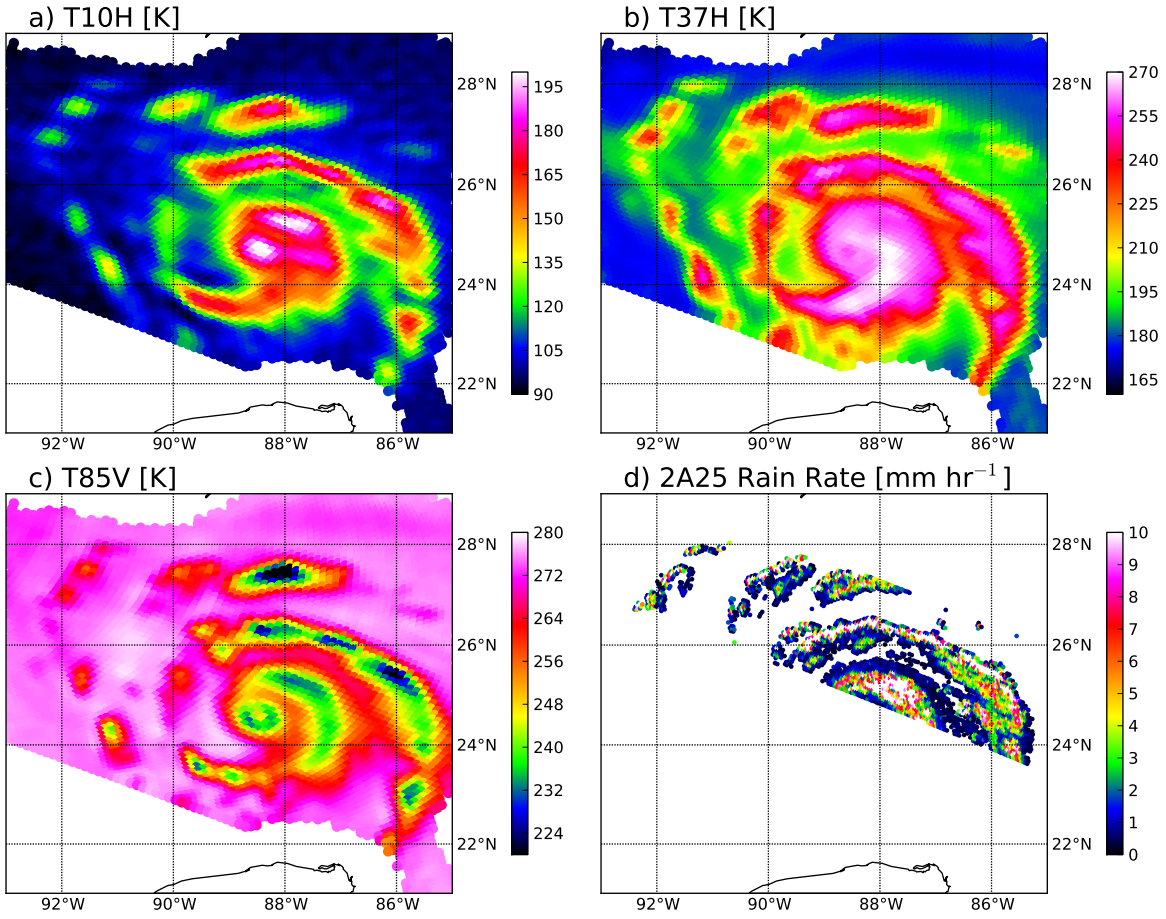
Step 2: Collect sensitivity from the desired variable (e.g. rain)

UW algorithm and 2A12

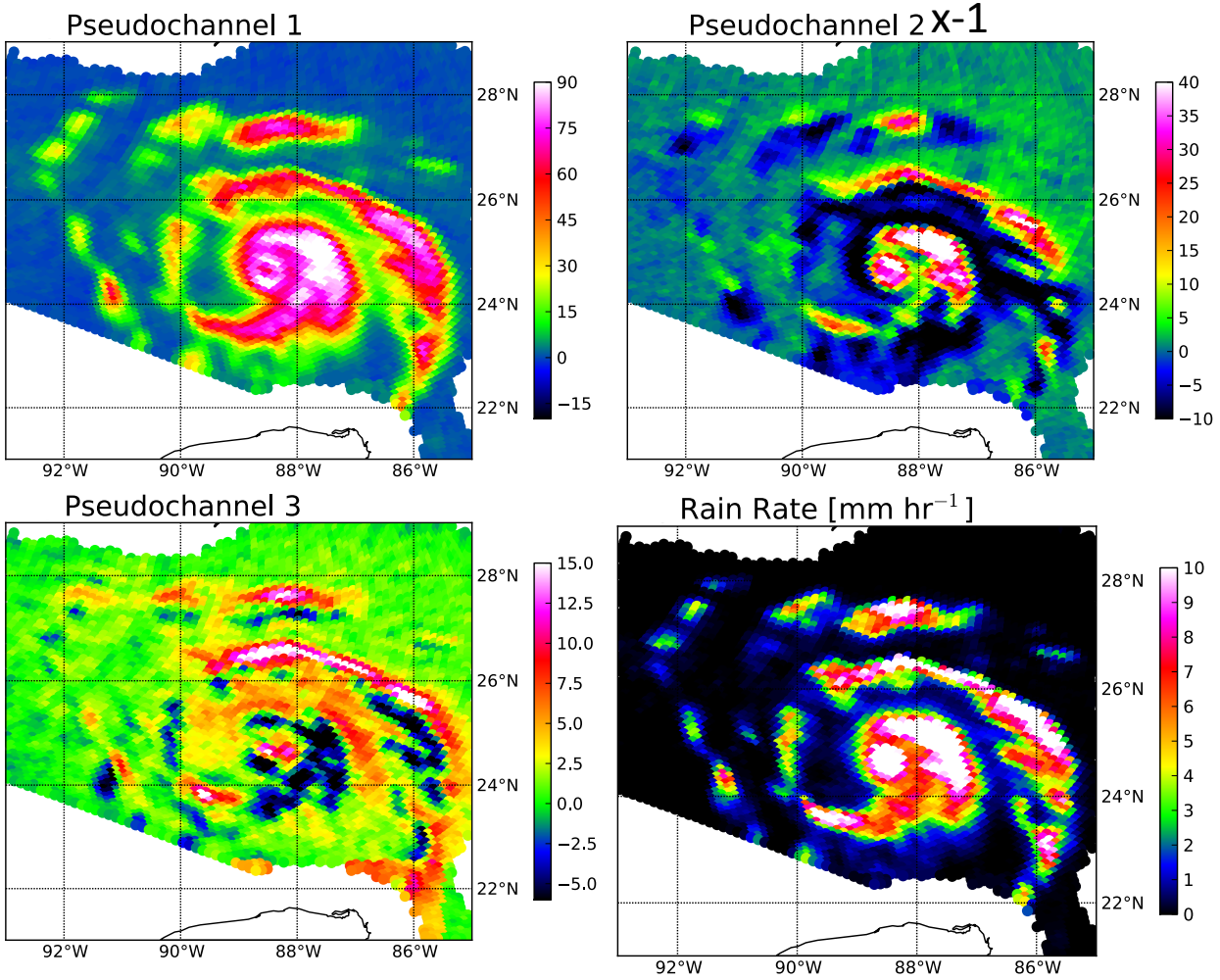


(Petty and Li 2013b)

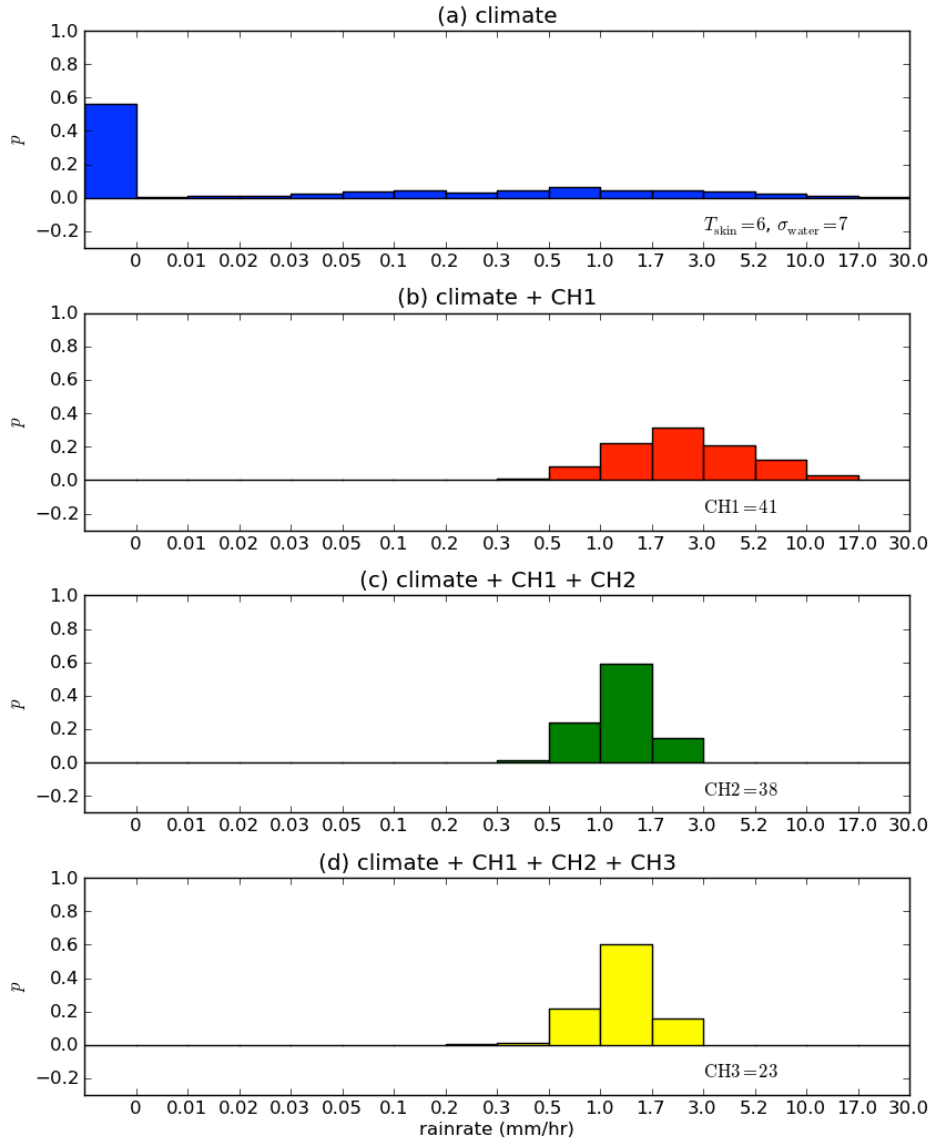
Hurricane Lili, 2 Oct, 2002
Physical Channels



Hurricane Lili, 2 Oct, 2002
Pseudo-channels



Posterior PDFs



So Far…

- UW algorithm for RR retrieval shows significant improvement.
- Leading features of storms to determine rain-rate revealed:
  - CH1: emission of cloud liquid water
  - CH2:
    - >0: anvil of precipitating clouds
    - <0: ice scattering of storm clouds
  - CH3: responsible to storm edges and gradients
- How important are each CHs?

Information Theory

- Shannon Entropy Difference
  - Measures changes in dispersion
  - (Shannon, 1948, 1956)
- Relative Entropy
  - Measures surprise
  - (Kullback and Leibler, 1951)
  - (Kullback 1997)
- Research:
  - Radar signals (Xu, 2006)
  - Electrical signal analysis …

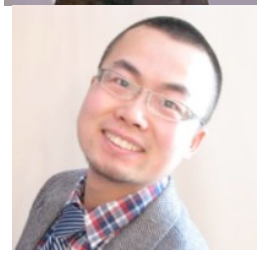
Shannon Entropy

`Dispersion Index'

$$SE \equiv -\sum p_i \ln p_i$$

$$\Delta SE(p \to q) = SE_q - SE_p$$

Shannon Entropy
`Dispersion Index'



$$p : \{0.5, 0.5\} \rightarrow q : \{0.9, 0.1\}$$

$$\Delta SE(p \rightarrow q) = SE_q - SE_p = 0.33 - 0.69 = -0.36$$

Relative Entropy

`Surprise Index'

$$RE(p \to q) \equiv \sum q_i \ln [q_i/p_i]$$

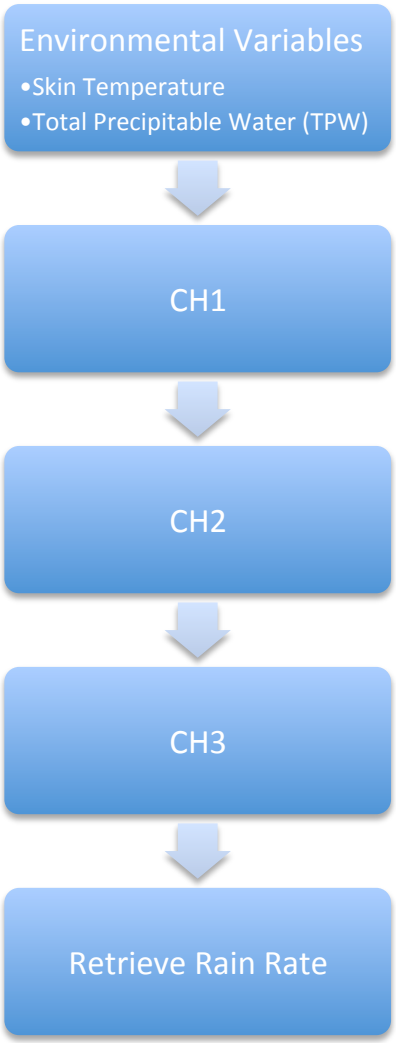
Relative Entropy

`Surprise Index'

$$p : \{0.5, 0.5, 0.0\} \rightarrow q : \{0.05, 0.05, 0.9\}$$

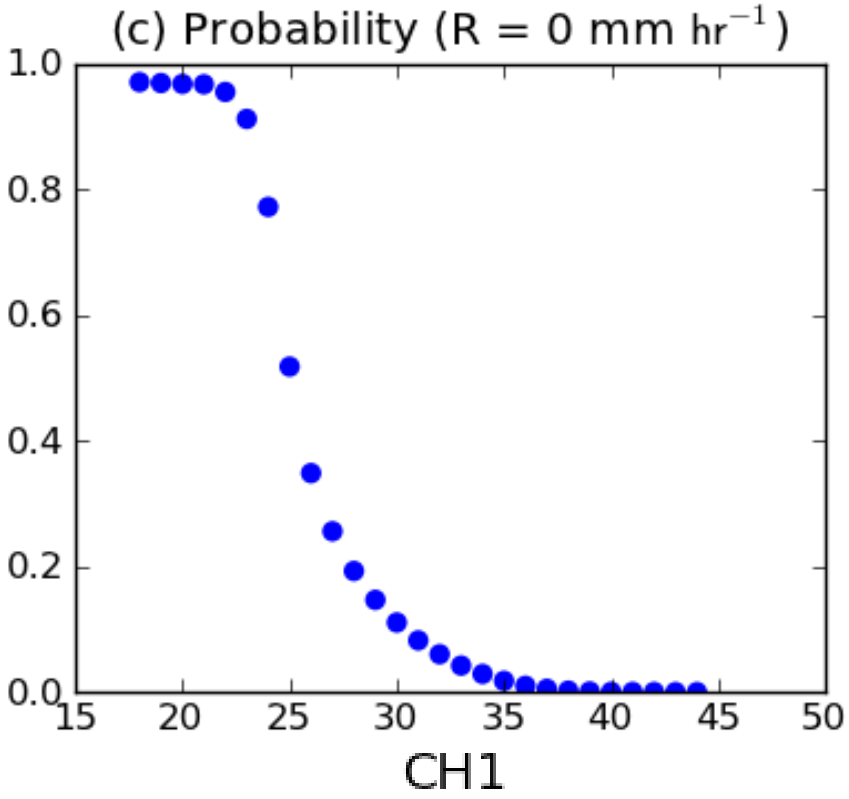
$$RE(p \rightarrow q) = RE(q, p) = \sum q_i \ln(q_i/p_i) = (-0.1) + (-0.1) + \infty = +\infty$$

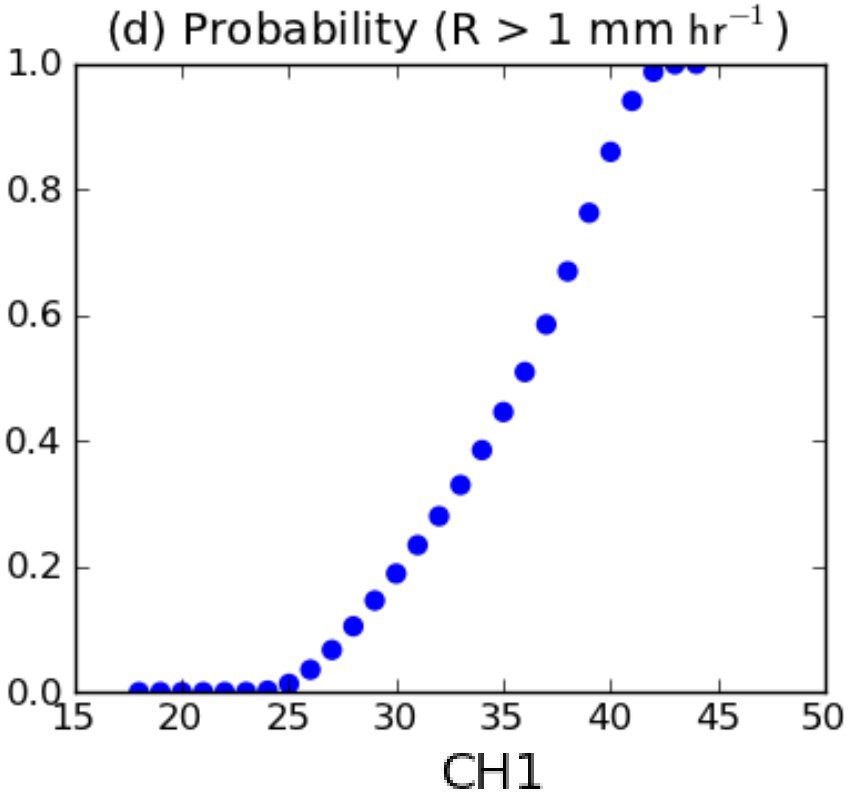
Necessary Condition



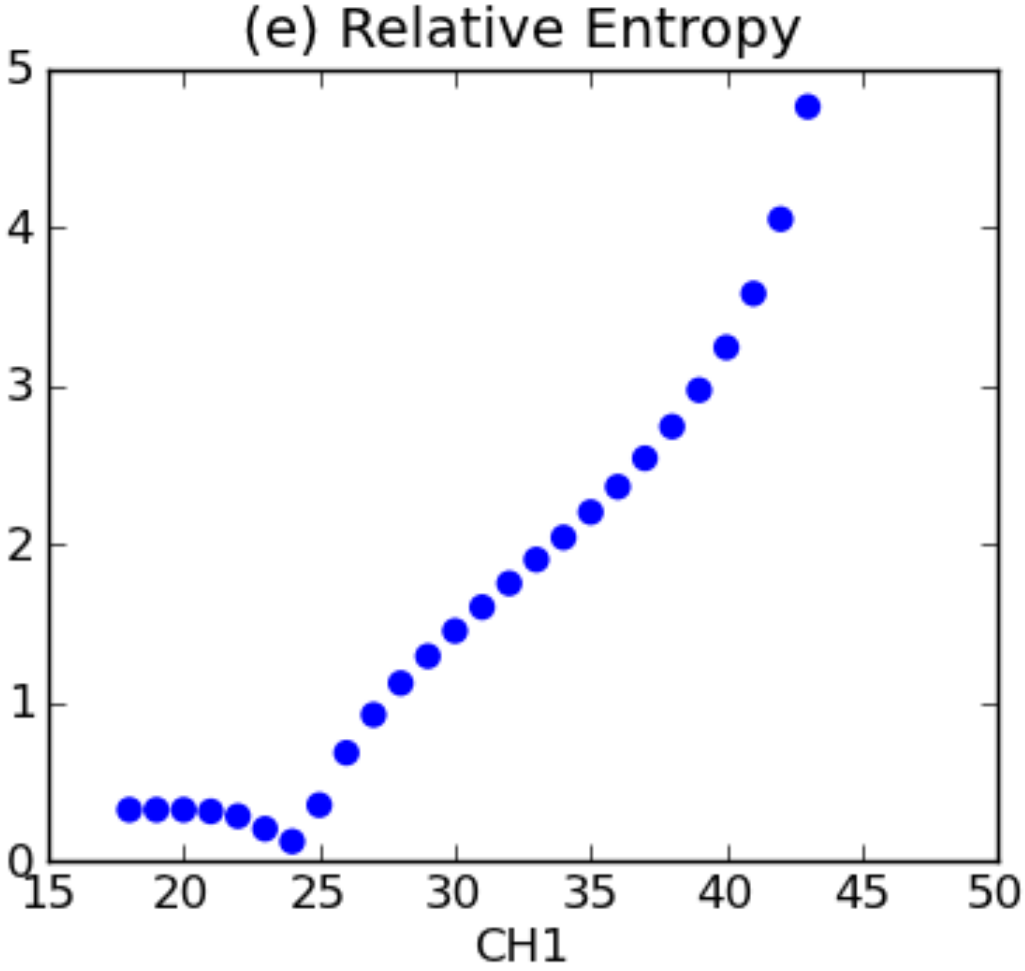
Climatology Data

CH1: Cloud Liquid Water Emission Precipitation Distribution

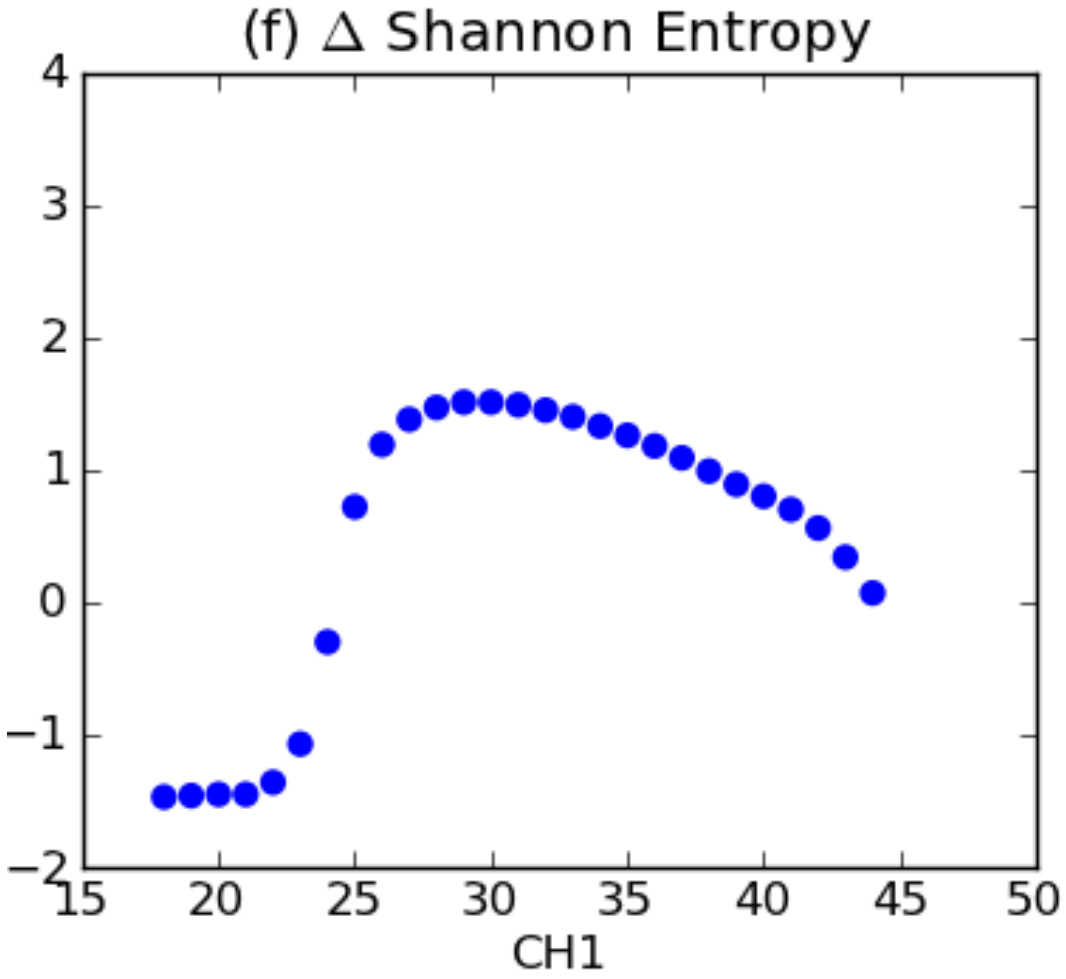




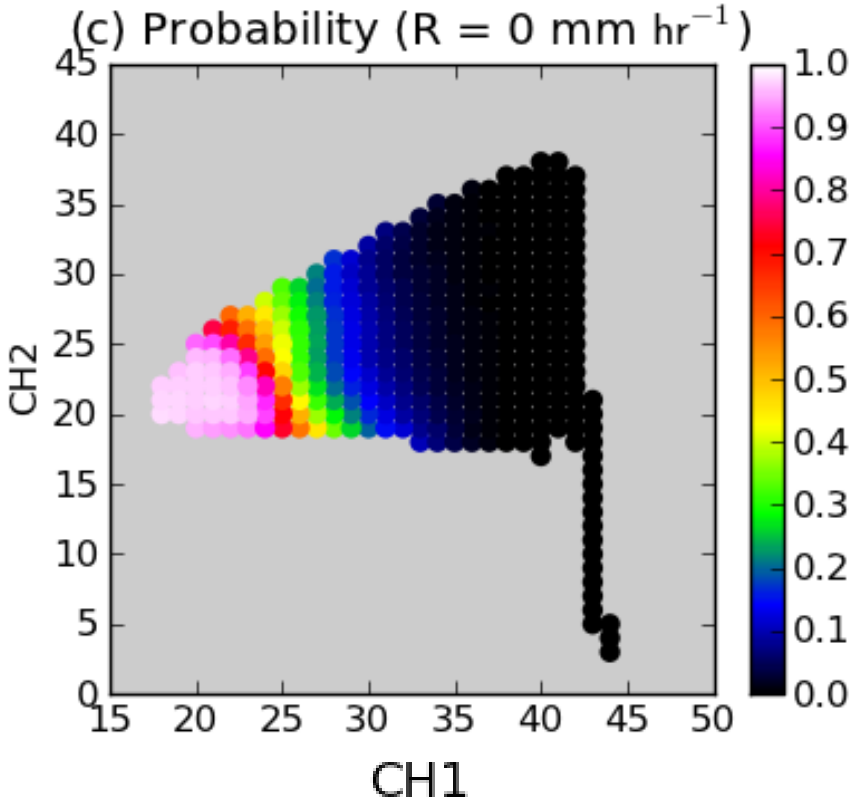
CH1: Cloud Liquid Water Emission ‘Surprises’

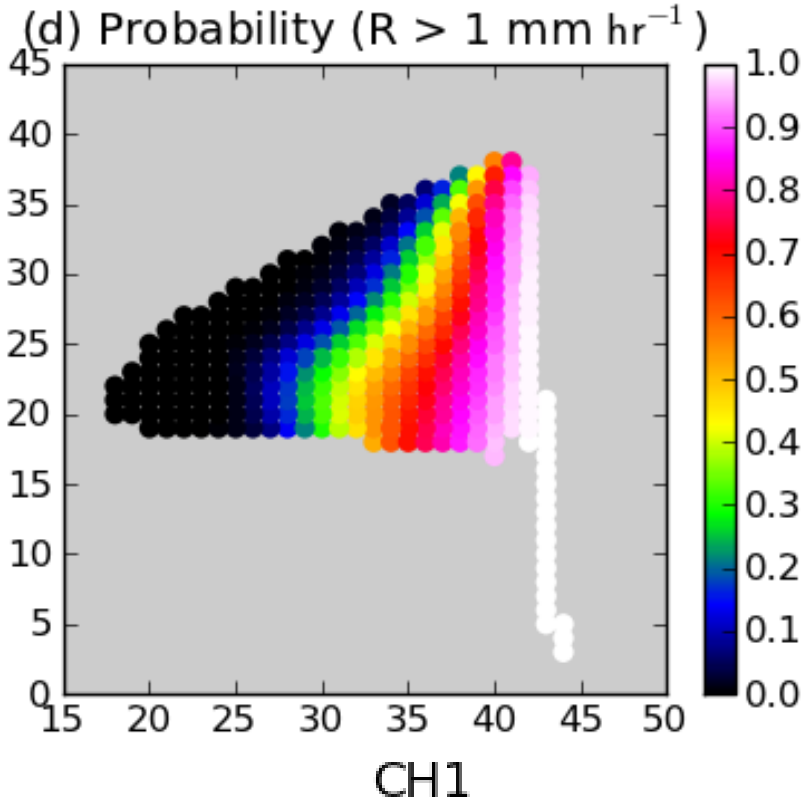


CH1: Cloud Liquid Water Emission ‘Dispersion’

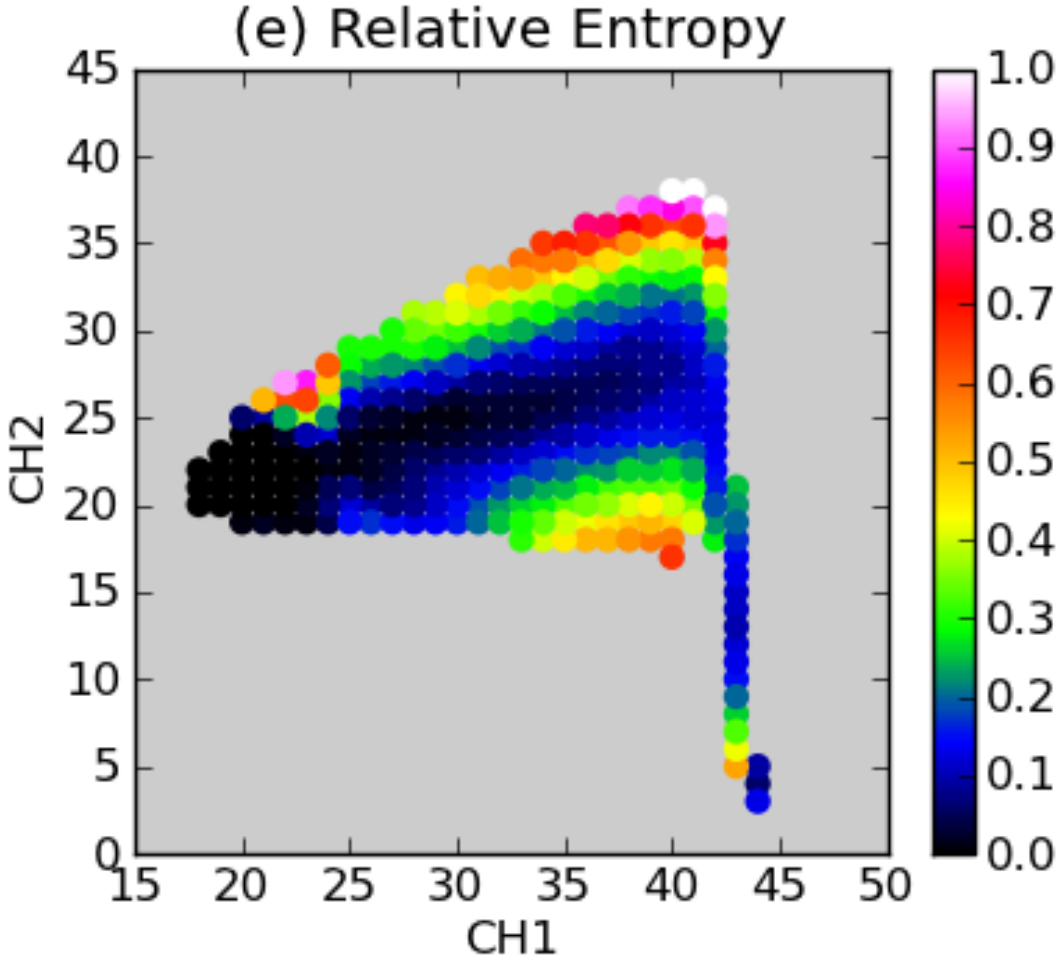


CH2: Anvil v.s. Deep Convection Precipitation Distribution

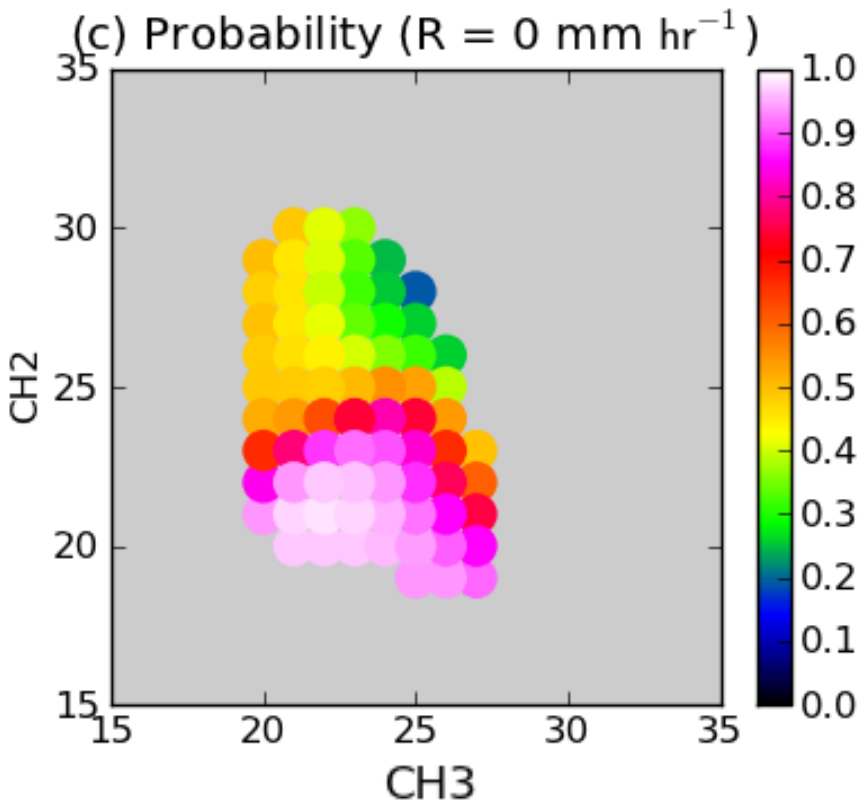


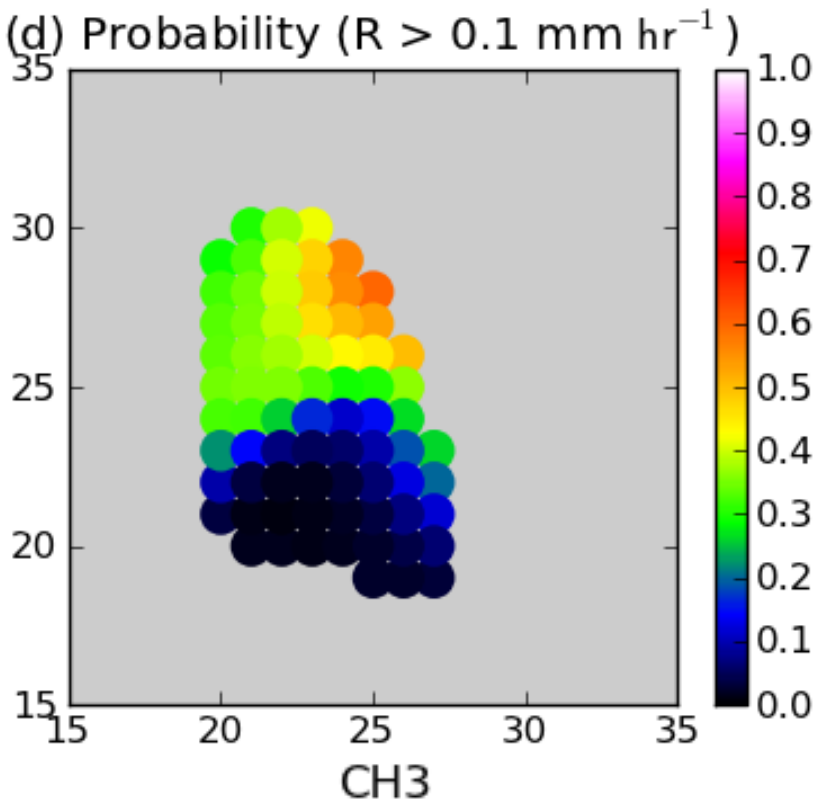


CH2: Anvil v.s. Deep Convection 'Surprise'



CH3
Low Rain Rate Retrieval





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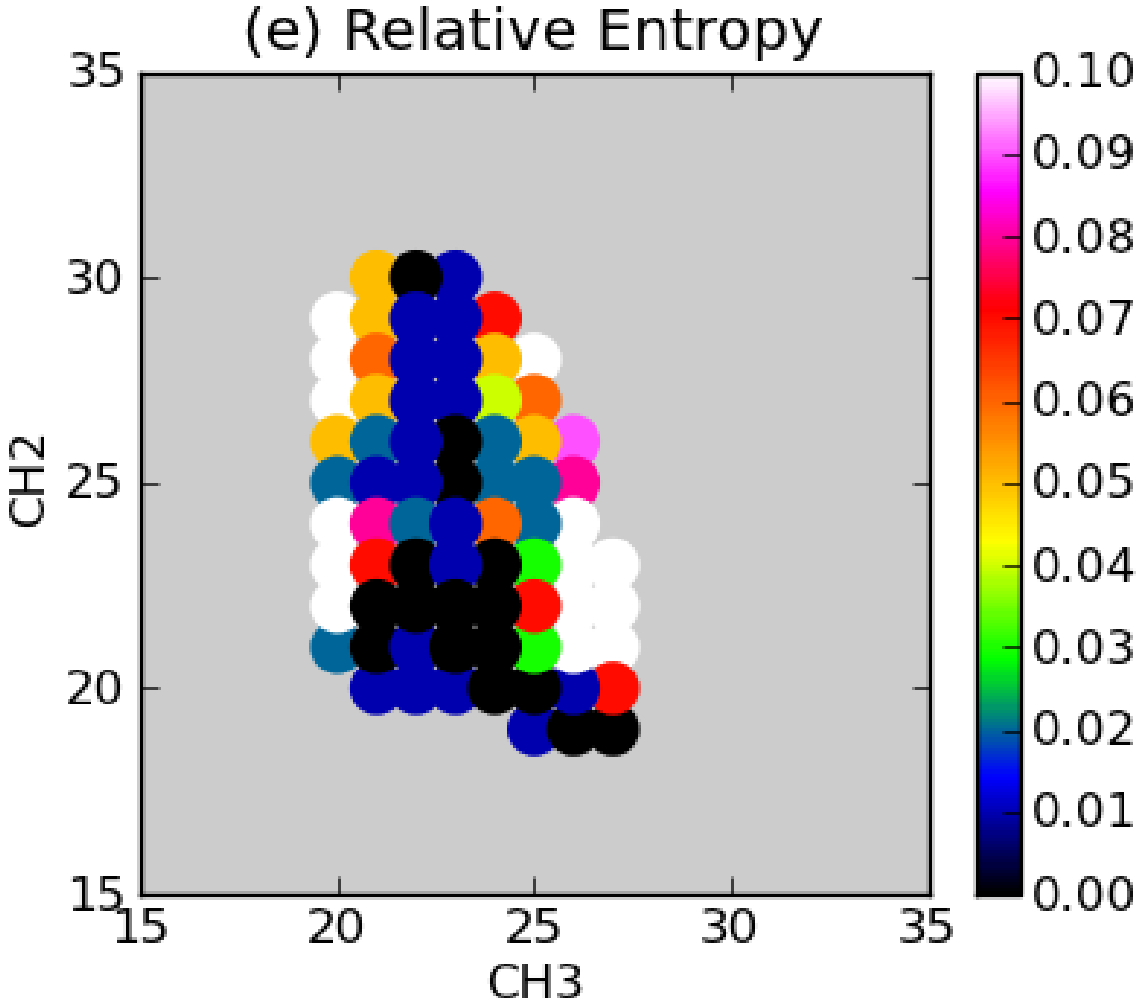
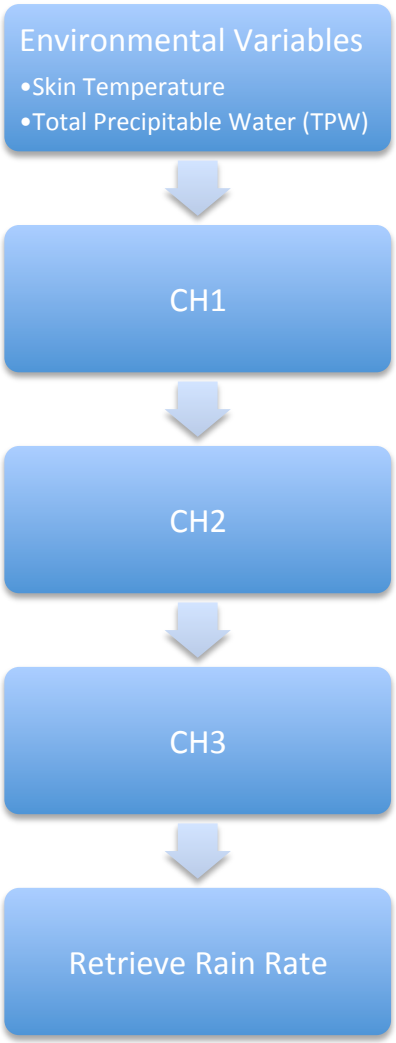
Low Rain Rate Retrieval

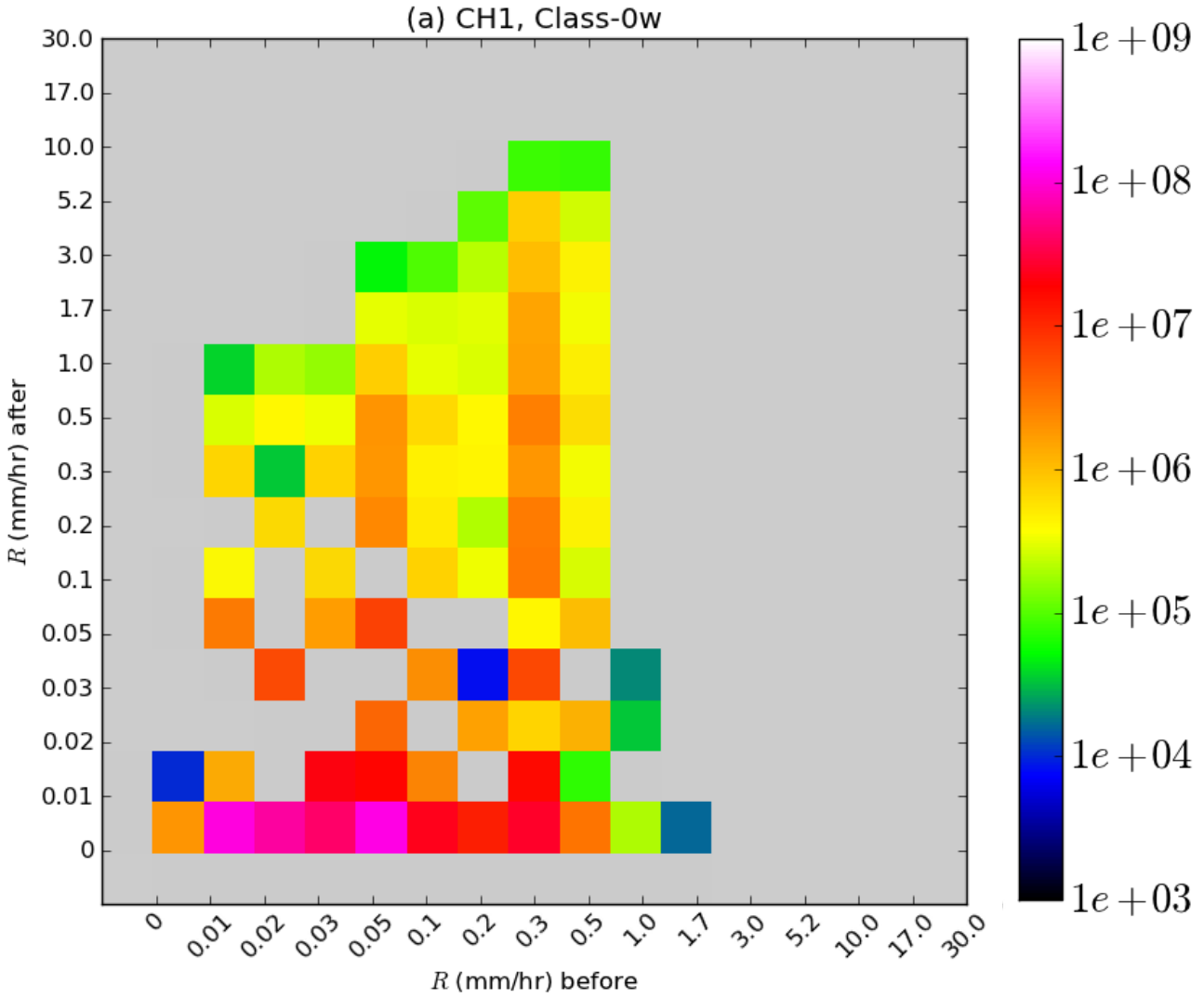


Sufficient Condition

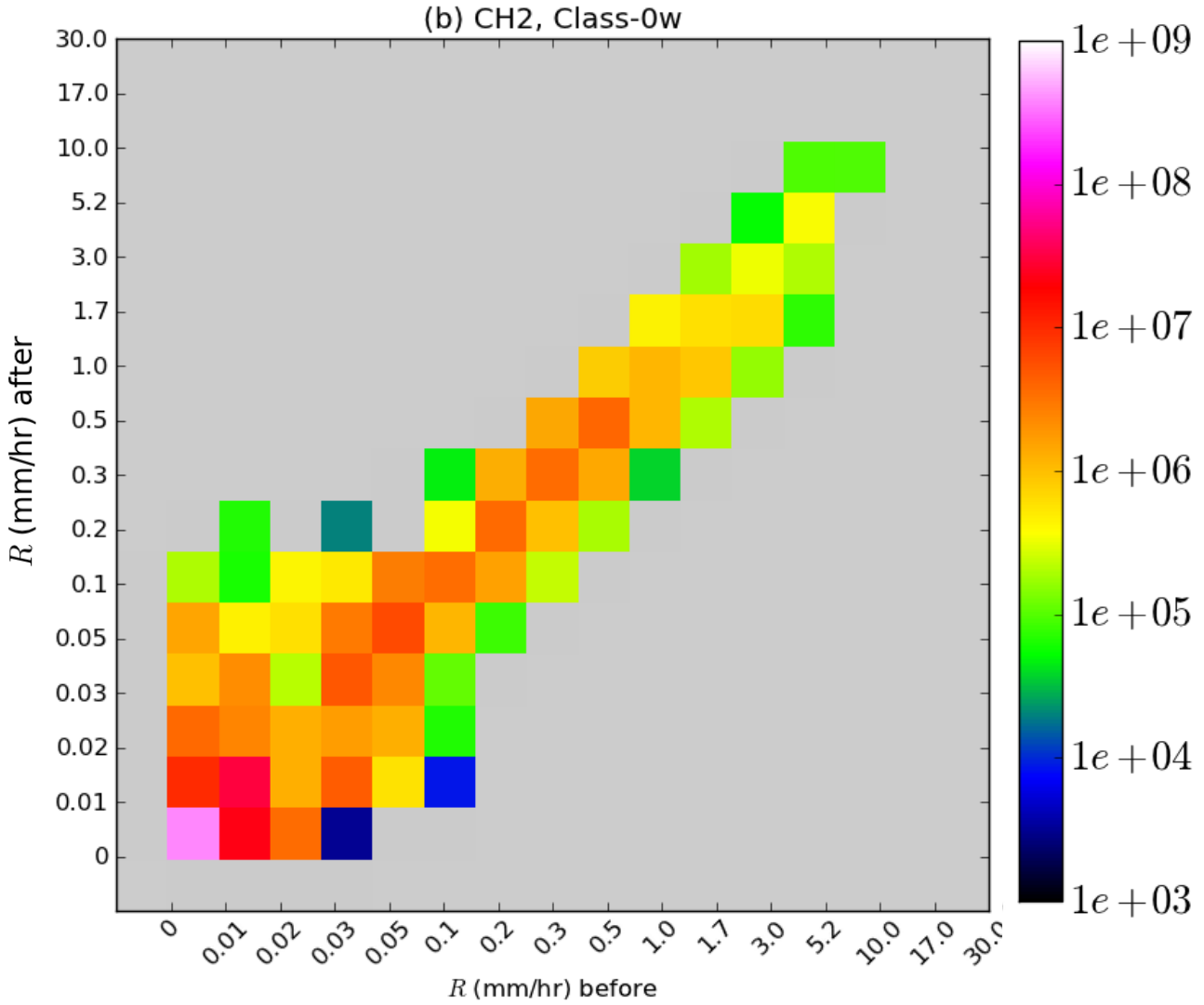


Climatology Data

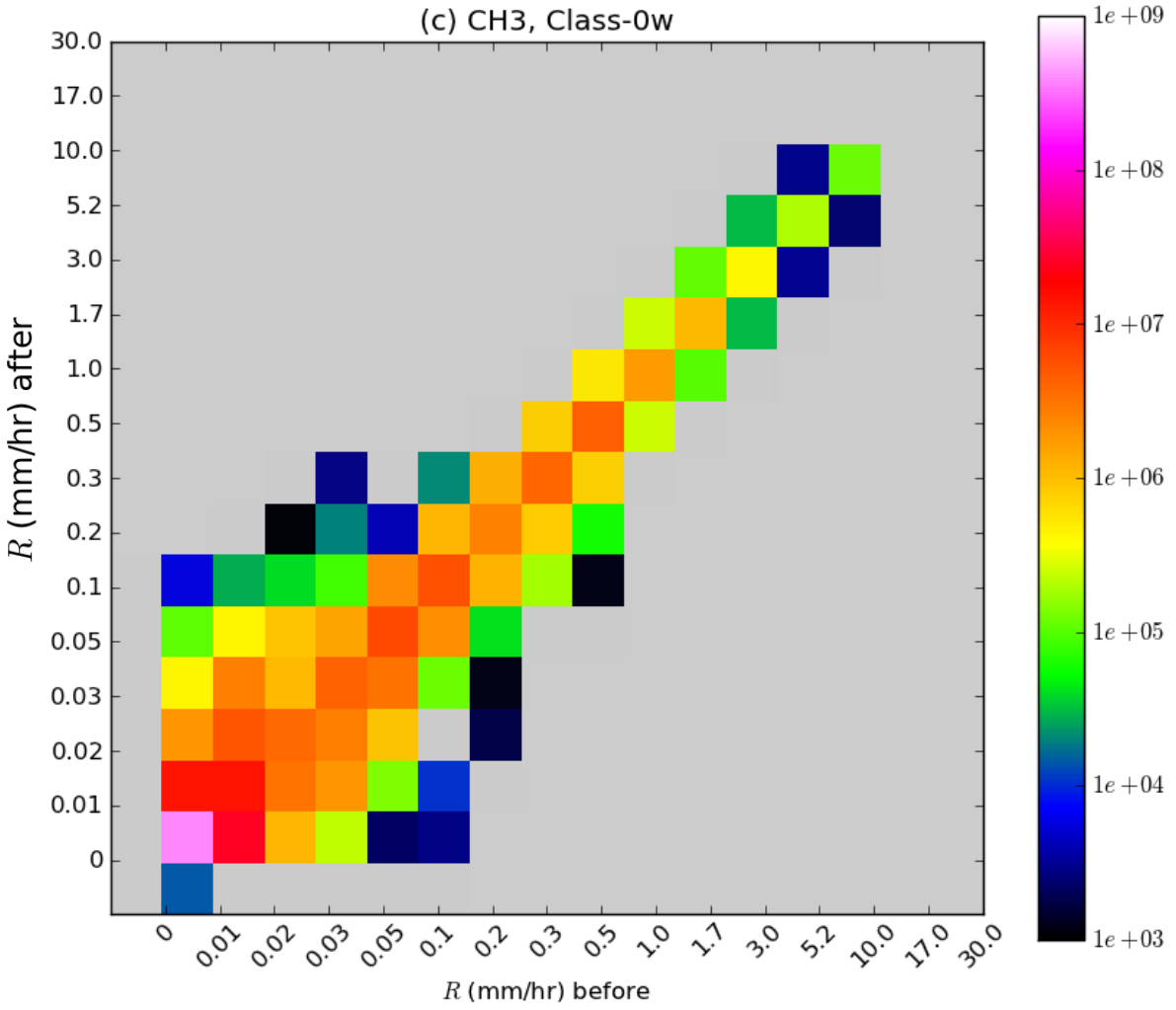
Information content – Sufficiency Adding CH1



Information content – Sufficiency Adding CH2



Information content – Sufficiency Adding CH3

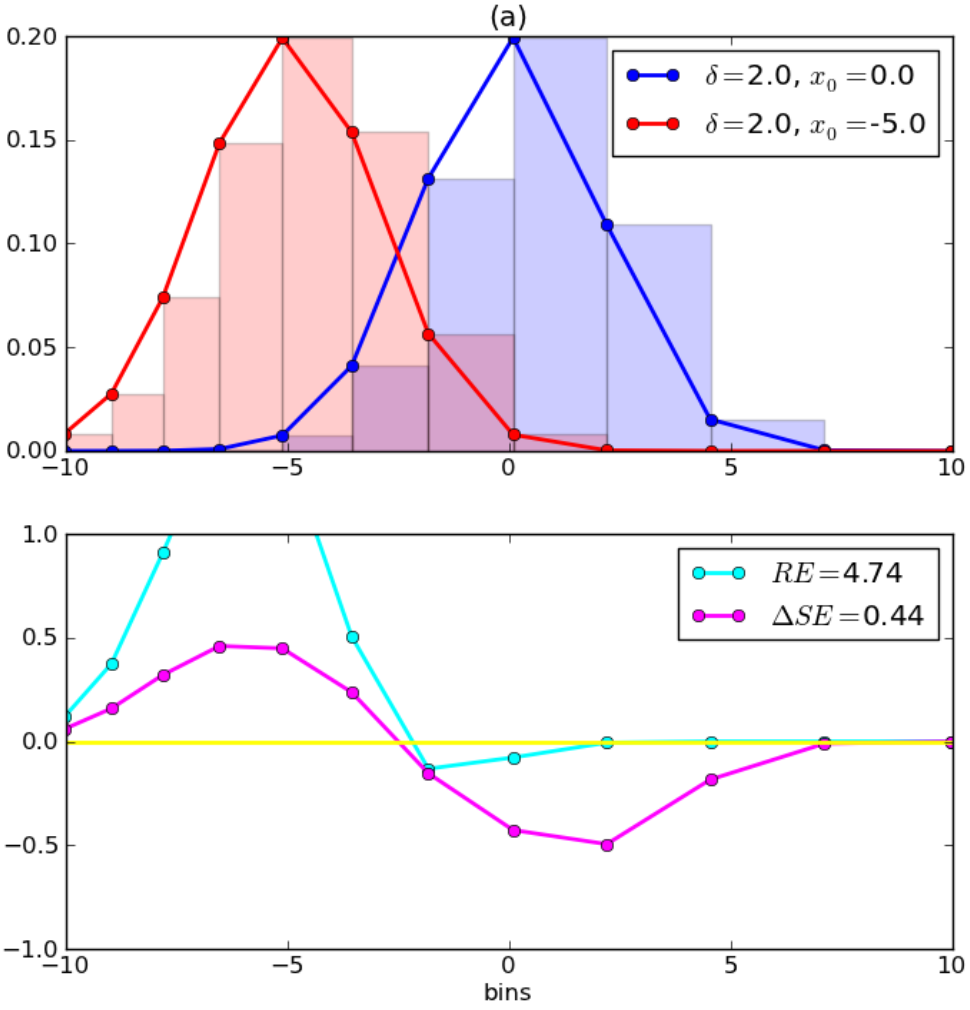


Conclusions

- CH1 and CH2: major information content
- CH3: little information content
  - Exceptions: at rare combination of CH1 and CH2
- Adding CH4:
  - greatly increases memory requirement
  - Reduced sample density
  - provides less information content

Questions?

Relative Entropy `Surprise Index'



Shannon Entropy
`Certainty Index'