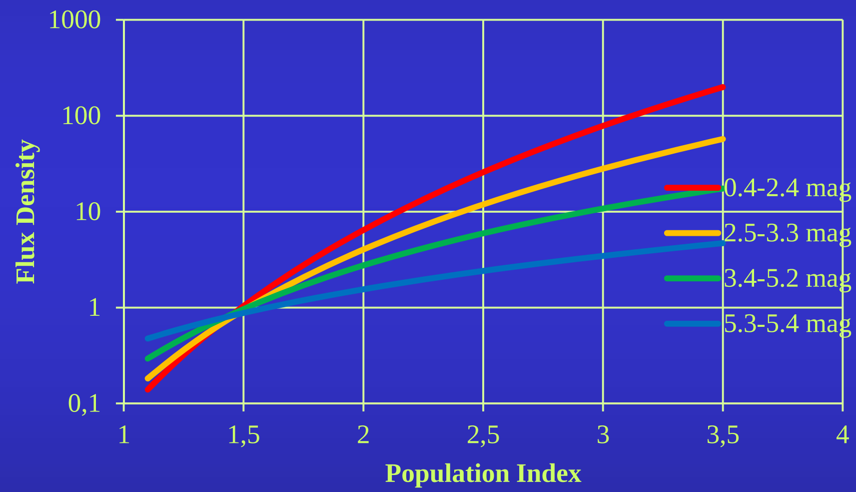
Obtaining Population Indices from Video Observations of Meteors



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Agenda

- Introduction: Population Index
- Derivation of a New Procedure
- Optimization of the New Procedure
- Preliminary Results

Introduction: Population Index (I)

- The population index (r-value) describes the brightness distribution in a meteor shower.
  - Meteor count up to brightness m+1 / meteor count up to brightness m.
  - Cumulative meteor counts!
- Population index is vital for the calculation of ZHR and flux densities:
  - $ZHR = (MC * r^{6.5-LM} * F) / (T_{eff} * (\cos ZD)^{\gamma})$
  - $FD = (MC * r^{6.5-LM}) / (T_{eff} * (\cos ZD)^{\gamma} * CA)$
- The more the limiting magnitude LM deviates from 6.5 mag, the bigger is the impact of the r-value on ZHR and flux density FD.
  - Video cameras often have a stellar limiting magnitude of only 3...4 mag.
  - Example SPE 2013: r=3.0 → FD_{Peak}=70 r=1.4 → FD_{Peak}=2.

ZHR … Zenithal hourly rate
FD … Flux density
MC ... Meteor count
r ... Population index
LM ... Limiting magnitude
F ... Obstruction of FOV
T_{eff} ... Effective observing time
ZD ... Zenith distance of radiant
CA ... Collection area
γ ... Zenith exponent

Introduction: Population Index (II)

- So far, we calculated the flux density with „typical“ constant r-values taken from visual observations.
- Two standard procedures for population index calculation from visual observations:
  - One is based on cumulative meteor counts per meteor magnitude class.
  - One relies on the difference between the mean meteor magnitude and the limiting magnitude.
- Prerequisites: No systematic error in the
  - Brightness estimation of meteors.
  - Dependency of the meteor detection probability from their brightness.
  - Determination of the limiting magnitude.

Derivation of a New Procedure (I)

- Properties of video observations (MetRec):
  - Big differences between individual cameras (wide range of fovs an lms) ☹
  - Large errors in the determination of meteor magnitudes. ☹
  - Precise measurement of size of fov, effective observing time and lm. ☺
  - Detection probability depends only on the meteor bright and velocity and is independent of the position inside the field of view or the time. ☺
- The standard procedure is not suitable for video observations. ☹
- Take advantage of the disadvantage: Because of the large variety in cameras, the meteor count resp. flux density of individual cameras relative to their limiting magnitude can be directly used to calculate the population index.

Derivation of a New Procedure (II)

- First an illustrative explanation with a totally fictitious example...

Fish-eye camera
fov 180°, lm +2 mag

Image-intensified camera
Fov 60°, lm +6 mag

Leo 1998
(r=1.4)

100 LEO
in 5h

Ratio 1:2

200 LEO
in 5h

Gem 1996
(r=2.6)

20 GEM
in 5h

Ratio 1:10

200 GEM
in 5h

The ratio depends on the population index

Calculate a
table of
expected ratios

r	Ratio
1.4	1:2
1.6	1:3
1.8	1:4
2.0	1:5
2.2	1:6.5
2.4	1:8
2.6	1:10
2.8	1:12
3.0	1:14.5
3.2	1:17

r=2.0

Per 2014
(r=???)

40 PER
in 5h

Ratio 1:5

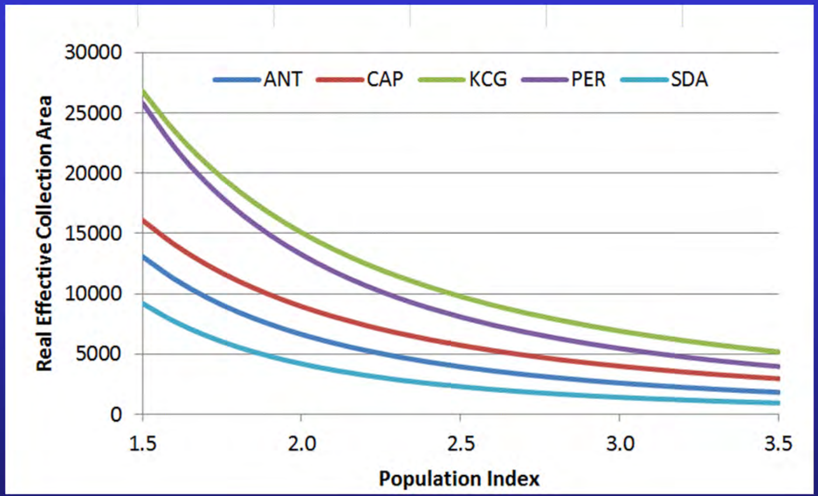
200 PER
in 5h

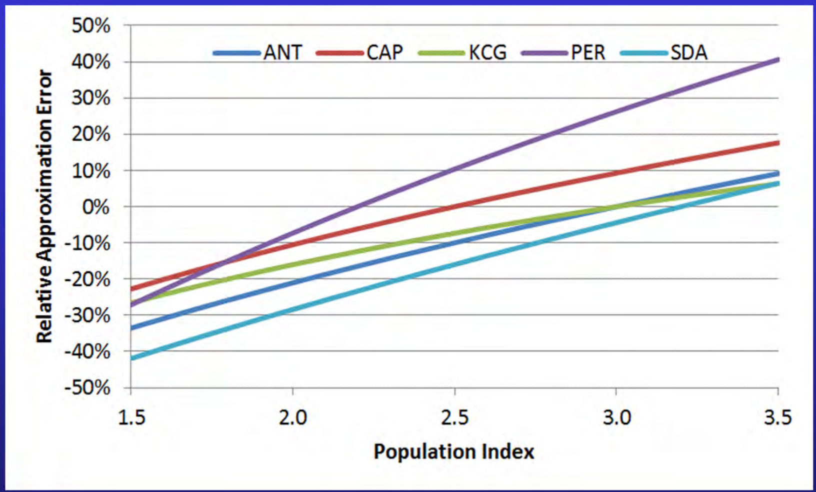
Derivation of a New Procedure (III)

- Idea: Calculate the flux density of each camera for each r-value and chose the one where the flux of all cameras agrees best.
- Prerequisite: The dependency of the flux density from the population index must be calculated quickly to find the best r-values.
- The dependency of the flux density from r is non-linear. ☹
  - Precise formula: $FD = MC / (T_{eff} * (\cos ZD)^{\gamma} * \Sigma_{pix} (CA / r^{6,5-MLM}))$
  - Stellar is replaced by meteor LM (which depends on the angular velocity).
  - Some factor are constant over the full field of view (Teff, ZD) and some vary from pixel to pixel (CA, MLM).
  - Determination of the collection area by accumulation over all pixel Σ_{pix}.
- Need to find an approximation for the dependency of FD from r.

Derivation of a New Procedure (IV)

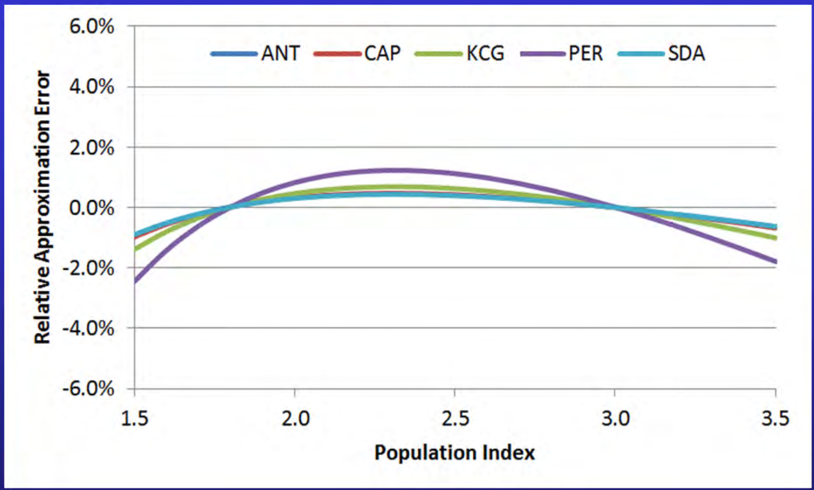
- First approximation: Replace MLM per pixel by an average meteor limiting magnitude AVGMLM.
- $FD \approx MC * r^{6,5\text{-}AVGMLM} / (T_{eff} * (\cos ZD)^{\gamma} * \Sigma_{pix}\ CA)$
  - Pull the constant term $r^{6,5\text{-}AVGMLM}$ out of the pixel sum.
  - Large approximation errors found based on data from August 2013. ☹

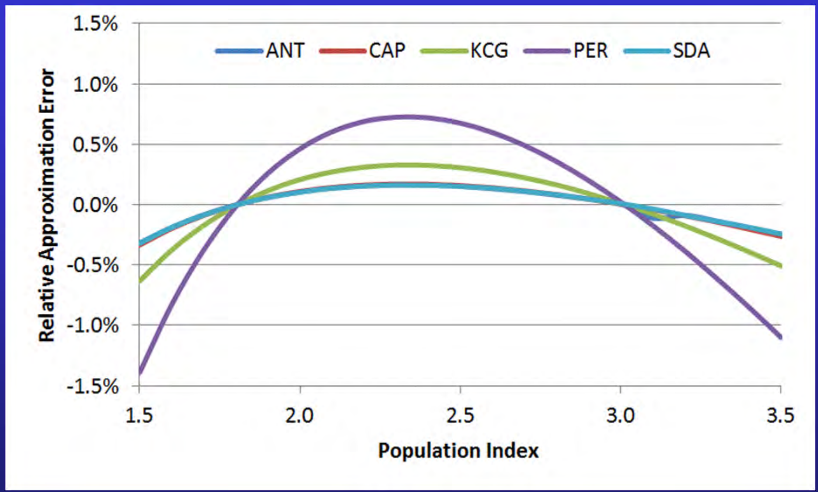




Derivation of a New Procedure (V)

- Better approximation: Calculate the effective collection area per night for different r-values and fit a parametric function.
  - Dependence of the effective collection area (or flux density) from the population index can be well approximated by a power function $a * r^b$. ☺
- Best approximation: Calculate $a * r^b$ per <u>minute</u>, not per <u>night</u>.



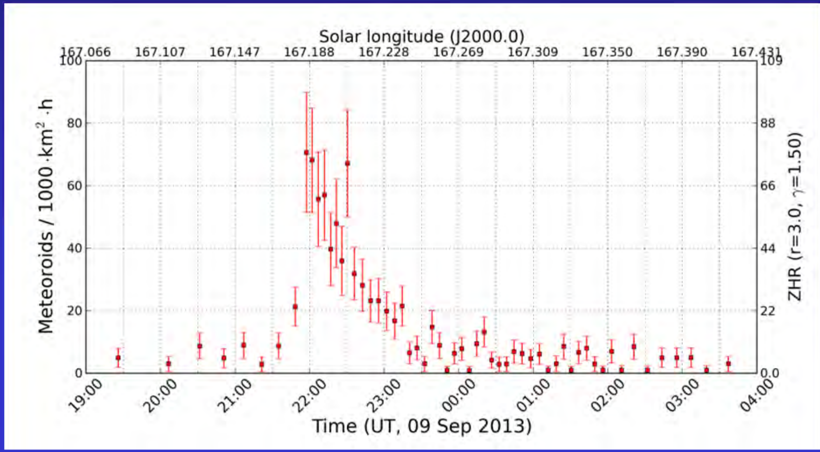


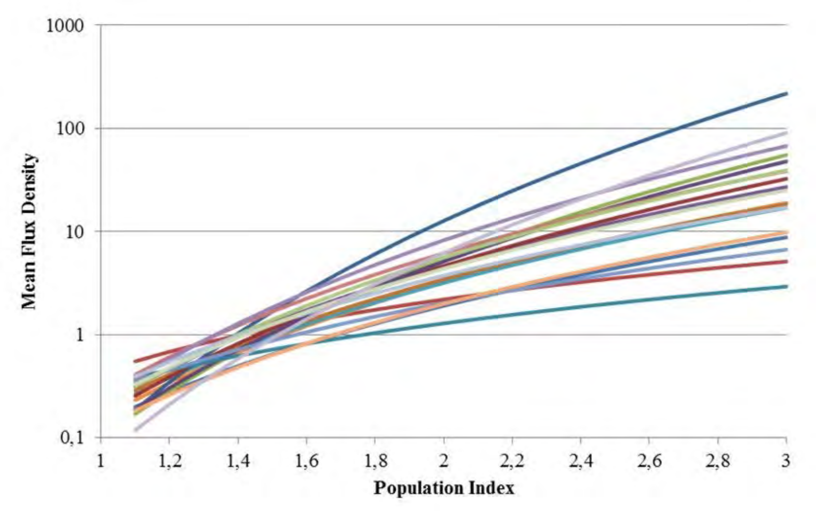
Derivation of a New Procedure (VI)

- Since the non-linear dependency of the flux density FD from the population index r can be calculated with a simple formula $a * r^b$, we can now convert the flux density for a given r-value r_{old} to any values r_{new} with a simple correction factor $CF = r_{old}^b / r_{new}^b$
  - Scaling factor *a* is canceled out.
  - Exponent *b* is calculated and stored for each shower and each minute.
- Procedure to calculate the population index (refined):
  - First calculate FD and *b* of each camera for some initial r-value.
  - Then try different r-values, estimate the new flux density, and choose the r-value where the flux density of all cameras agrees best.
  - At lm 6.5 mag the flux density is independent of r (vertical line).
  - The larger the deviation from 6.5 mag, the bigger the slope.

Derivation of a New Procedure (VII)

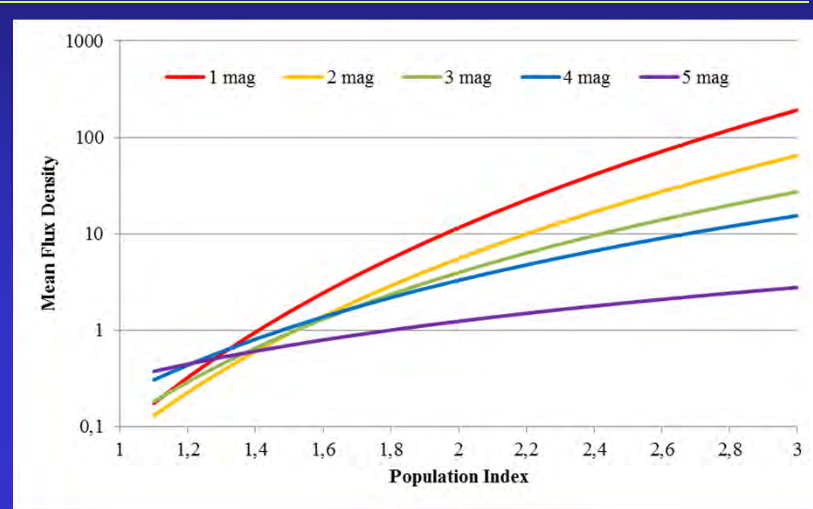
- Example: SPE on Sep 9, 2013
  - 21 active video cameras.
  - Many bright meteors.
  - FD over r in a logarithmic plot!
- Best intersection point is difficult to find ☹
  - Cameras have similar lm, so curves are nearly parallel.
  - Also sensitive cameras have clouded intervals with poor lm.
  - Basic principle ok, but pro-cedure needs to be optimized.

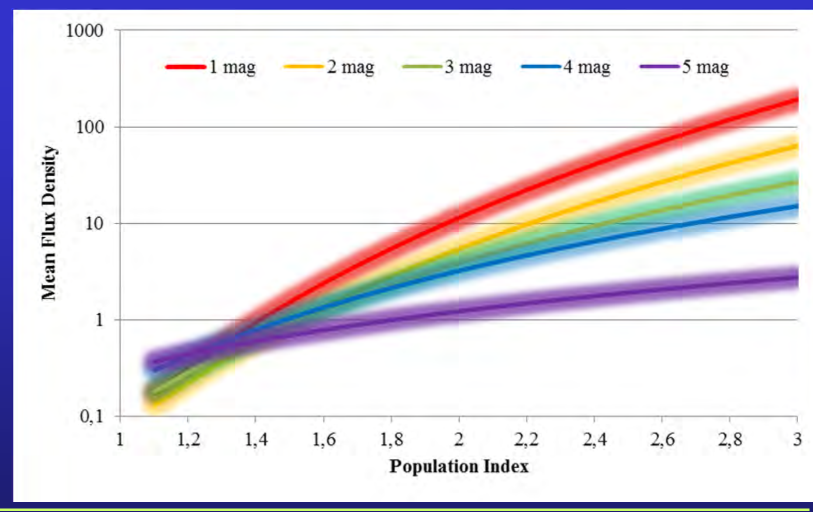




Optimization of the New Procedure (I)

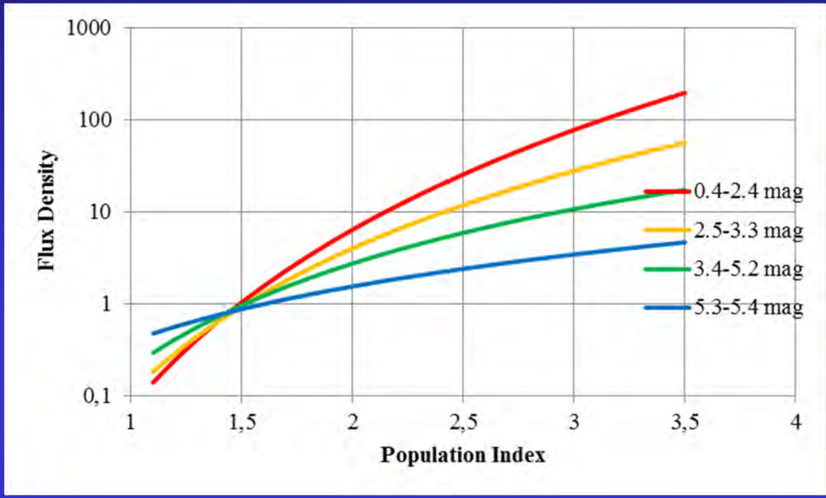
- Solution: Data are not accumulated by camera, but by meteor limiting magnitude.
  - Fewer graphs with bigger intersection angle. ☺
  - No problems with clouds. ☺
  - Still no single intersection point, so „blur“ the graphs and find the point of highest „intensity“.
- All graphs have the same weight and lm intervals are selected randomly. ☹



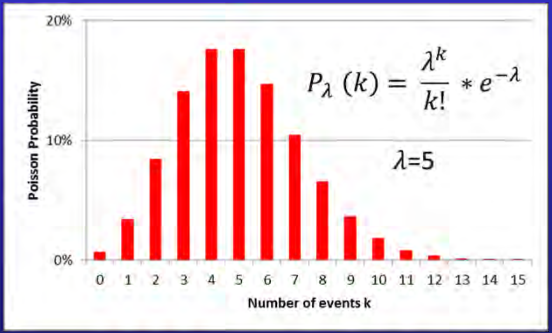


Optimization of the New Procedure (II)

- Solution: Data-driven selection of the lm intervals.
  - Each bin gets a fixed fraction of the effective collection area.
  - Use only intervals with lm >1.5 mag which have better accuracy.
  - Apply Poisson distribution to weight the individual graphs.

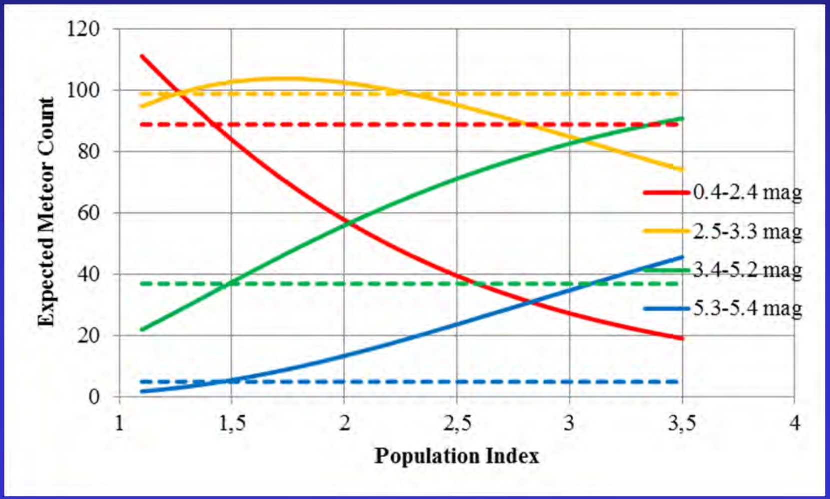


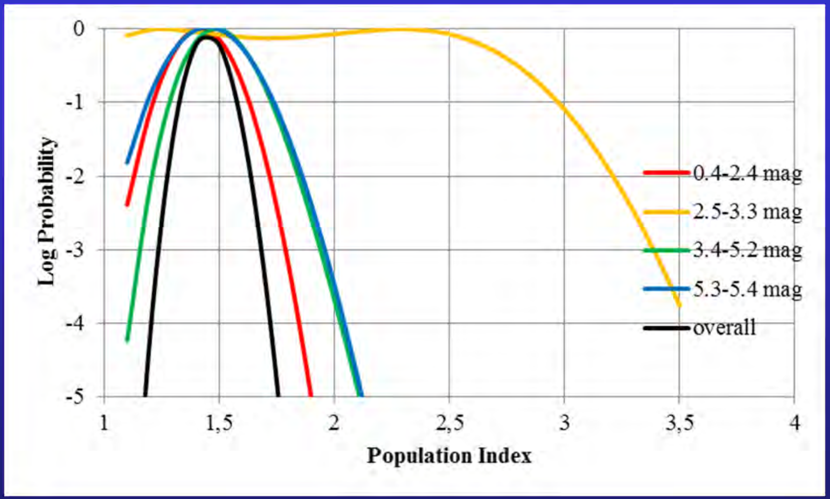
- Poisson distribution?
  - Given are random, independent events with a constant average rate λ per time unit.
  - The (discrete) Poisson distribution gives the probability, that in a particular time unit exactly k events occur.



Optimization of the New Procedure (III)

- Procedure
  - For each r-value we compute the collection area and which fraction of it falls into each lm class.
  - This tells us, which fraction of the total meteor count is expected in each lm class (λ).
  - That is compared to the observed meteor number (k) per lm class.
- $P_{\lambda}(k)$ yields the probability of r.
  - Logarithmic probabilities.



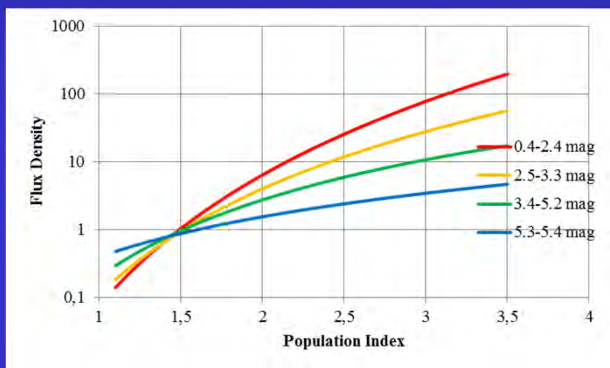


Optimization of the New Procedure (IV)

- Properties of the Poisson distribution:
  - The absolute number of meteors is automatically included in the weighting of each lm class. ☺
  - Mean lm classes, where the expected meteor count varies only little with the r-value, have only little impact. ☺
- Advantage of the new procedure: Robustness!
  - Independent of meteor brightness estimates. ☺
  - A possible systematic error in lm calculation has no impact, because all lm classes are affected in the same way. ☺
  - The meteor detection probability depending on lm has no impact, because all lm classes are affected in the same way. ☺
  - Zenith exponent has only a small impact.

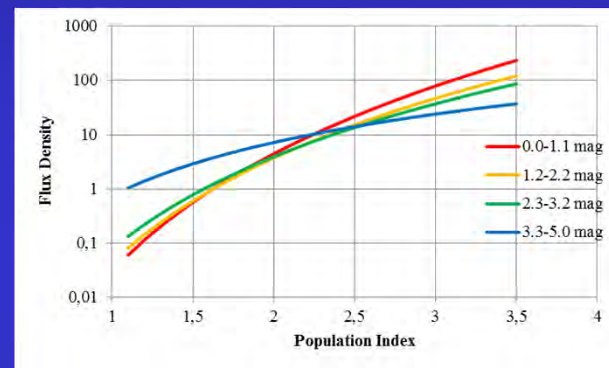
Preliminary Results (I)

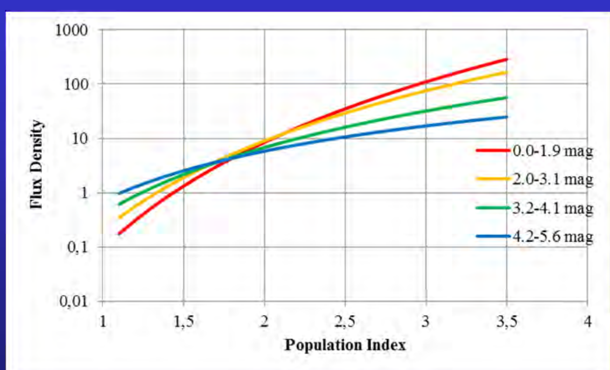
- During the development of the procedure, different meteor showers have been analysed „manually“.



SPE
Sep 9/10, 2013
r=1.4

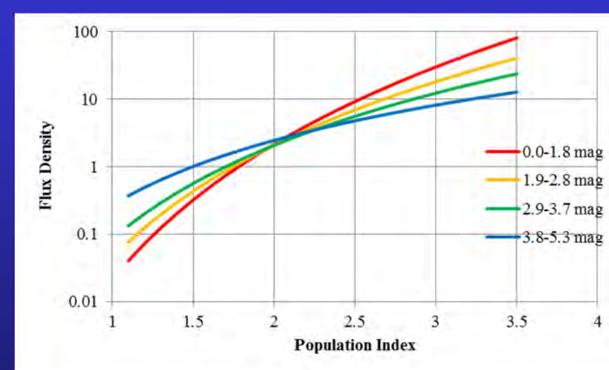
ORI
Oct 23/24, 2013
r=2.3





QUA
Jan 03/04 2014
r=1.8

LYR
Apr 22/23 2014
r=2.1

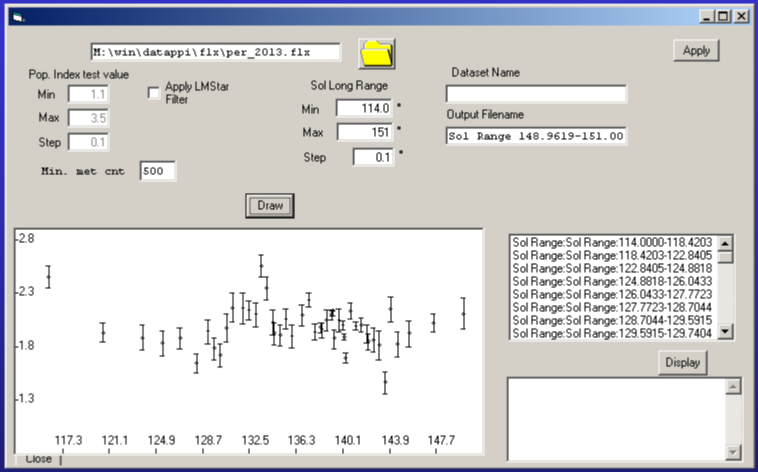


Preliminary Results (II)

- The aim is to obtain population index profiles „automatically“.
- We do not start at zero, but we can use all observations since April 2011 where lm in known to calculate r-profiles! ☺
  - The flux density and the power function exponent *b* that describes it‘s dependency on the r-value can be re-calculated for these data.
  - Time consuming task (one CPU month), but finished.

PER 2013

- Currently two programs are im-plementing the new procedure.
  - S. Crivello is working on the flux analyser tool for Win XP that reads FLX files, displays the data and calculates r-profiles.

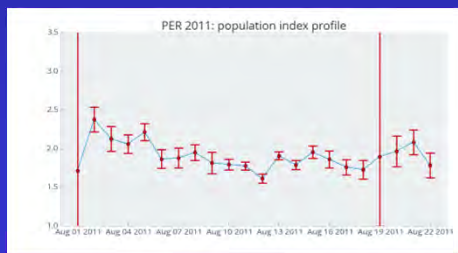


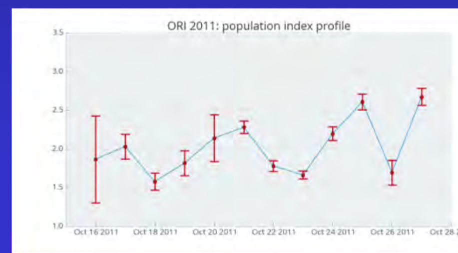
Preliminary Results (III)

- G. Barentsen is extending the flux viewer web application.

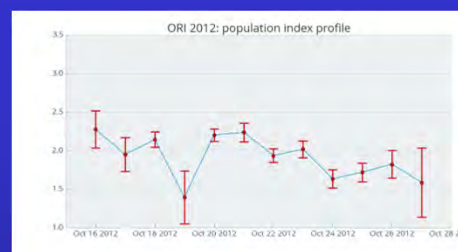
PER ORI GEM

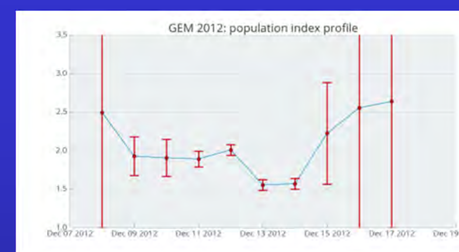
2011



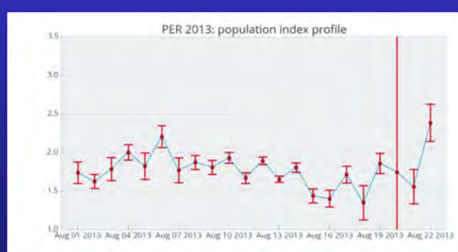


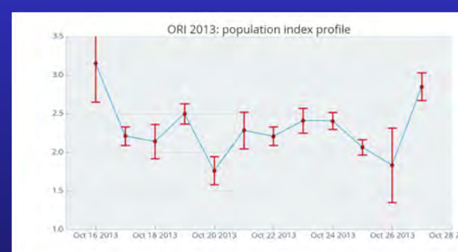
2012

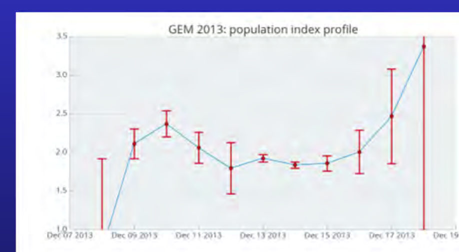




2013







Preliminary Results (IV)

- Work in progress, further optimization required (right parameter sets, best data selection criteria, error bars,…).
- There are different boundary conditions for population indices obtained from visual and video observations:
  - Video observations are using the absolute meteor magnitude (i.e. normalized to 100 km altitude), visual observation the apparent magnitude.
  - The observing direction (altitude, radiant distance) is properly accounted for only in case of video observations.
  - The effect of meteor motion on the limiting magnitude (fast meteors distribute their photons over more pixels) is only accounted for in case video observations.
- Thus, population indices obtained from visual and video data may not directly comparable with one another.

Thanks for your Attention

Questions!