Assimilative Real-time Models of HF Absorption at High Latitudes

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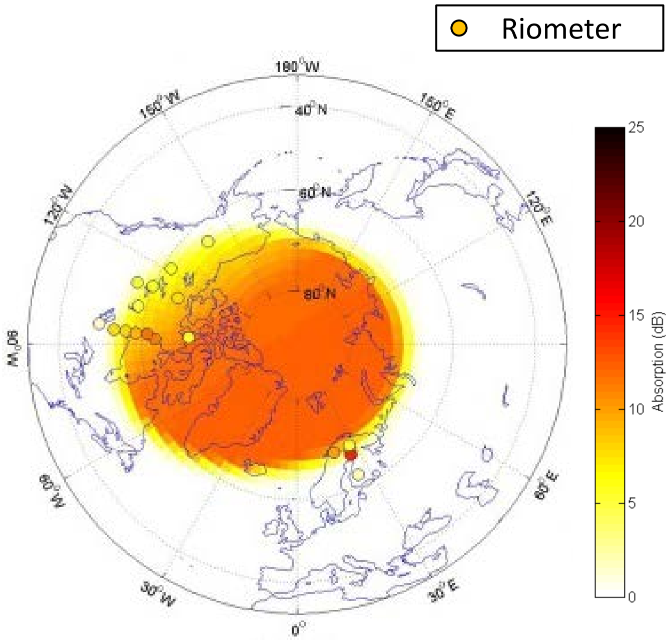
Overview

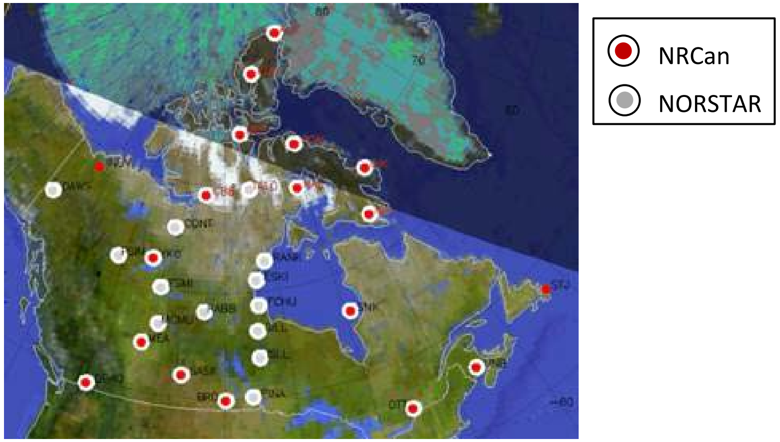
- A large array of riometers measure 30 MHz radio absorption
  - Data available in near-real time
- Polar cap absorption (PCA) models have been adapted to assimilate riometer measurements
- Model parameters are optimised in real-time
  - Age-weighted regressions to riometer measurements
  - Rigidity cut-off latitude also varied
- Ionospheric response at twilight is asymmetric
  - Optimise dawn/dusk parameters independently
- Also assimilate proton flux spectra from polar-orbiting satellites (POES)



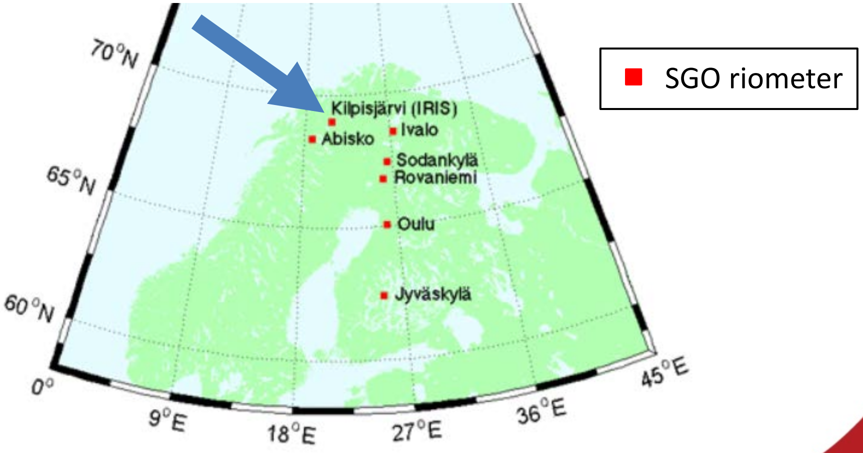
Map of predicted 30 MHz absorption during a polar cap absorption event, with riometer measurements (●)

Riometer measurements

- Riometers measure ionospheric absorption of cosmic background radiation at ~30 MHz
  - NORSTAR array
    - University of Calgary / Canadian Space Agency
    - 13 riometers
  - Natural Resources Canada
    - 18 riometers since 2006
  - Sodankylä Geophysical Observatory
    - 7 riometers
  - IRIS Kilpisjärvi
    - University of Lancaster, UK
- 94 Solar Proton Events in 1995-2010 period



[Image: D. Danskin/ Natural Resources Canada]



[Image: Sodankylä Geophysical Observatory]

Polar Cap Absorption model

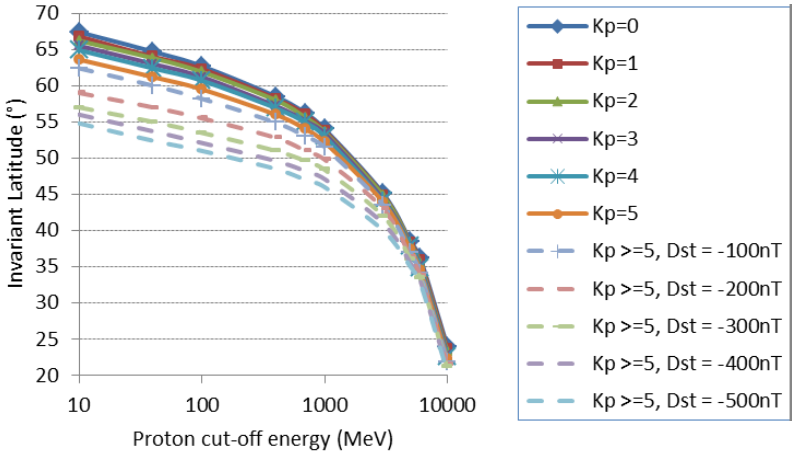
- **Model Type 1: (Energy Threshold model)**
  - E.g. DRAP model (Sauer & Wilkinson, 2008)

- Absorption, $A = m\sqrt{J(> \max(E_t, E_{cutoff})}$ (dB)

$J(> E)$ is the flux of solar protons with energy > E (measured at GOES satellite)
m, E_t are fixed parameters (specified for night and day ionospheres)
E_{cutoff} is the rigidity cutoff (due to geomagnetic field deflection)

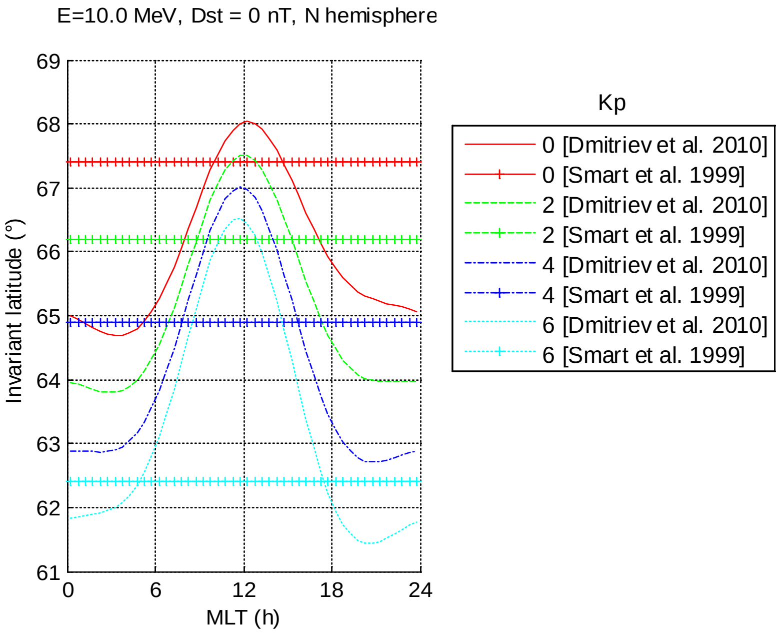
Rigidity Cut-off Latitude Models

Smart et al. 1999



- Applied in DRAP
- No magnetic local time (MLT) dependence

Dmitriev et al. 2010

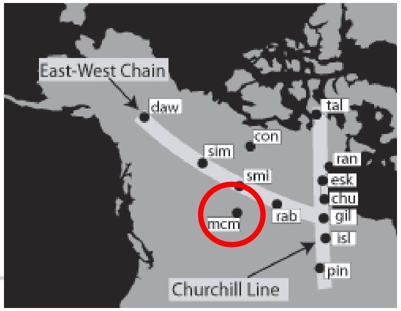


- Boundary ellipses fit to NASA POES proton flux measurements
- Low energy protons have magnetic local time (MLT) dependence

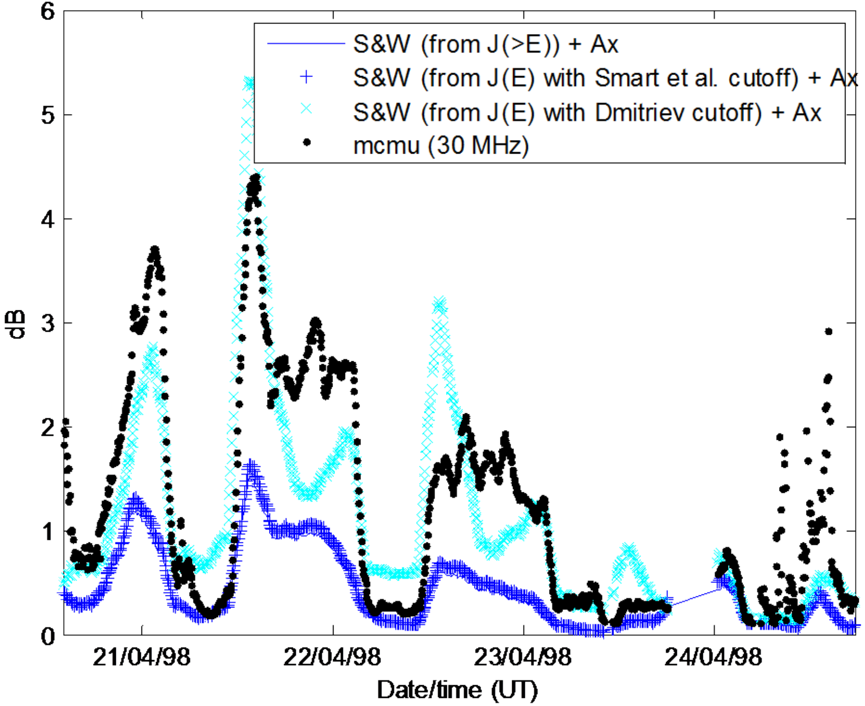
Smart et al., PROC. INT. COSMIC RAY CONF., 7, 337-340, 1999

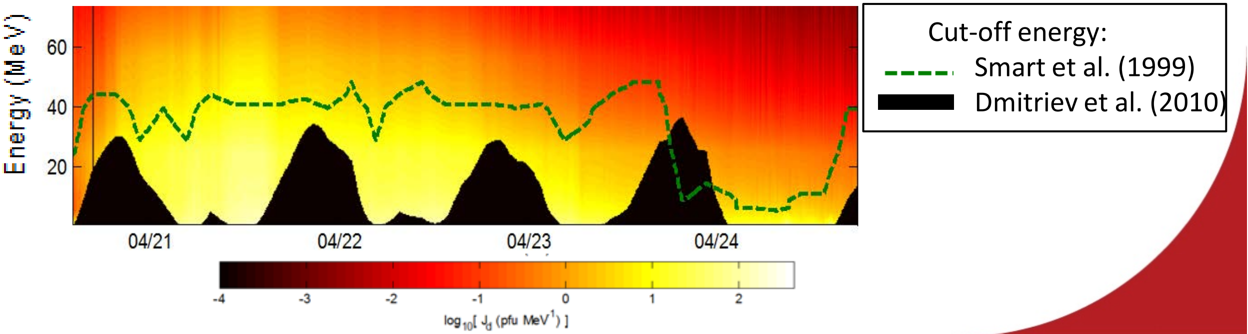
JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 115, A12244, doi:10.1029/2010JA015380, 2010

Dmitriev vs Smart Rigidity Cut-off



- The Dmitriev cut-off model improves on Smart model but predicts a regular midday recovery that isn’t always observed on riometers
- The Smart cut-off is improved by a 1-3° equatorward shift





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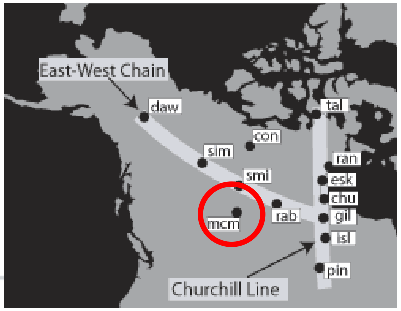
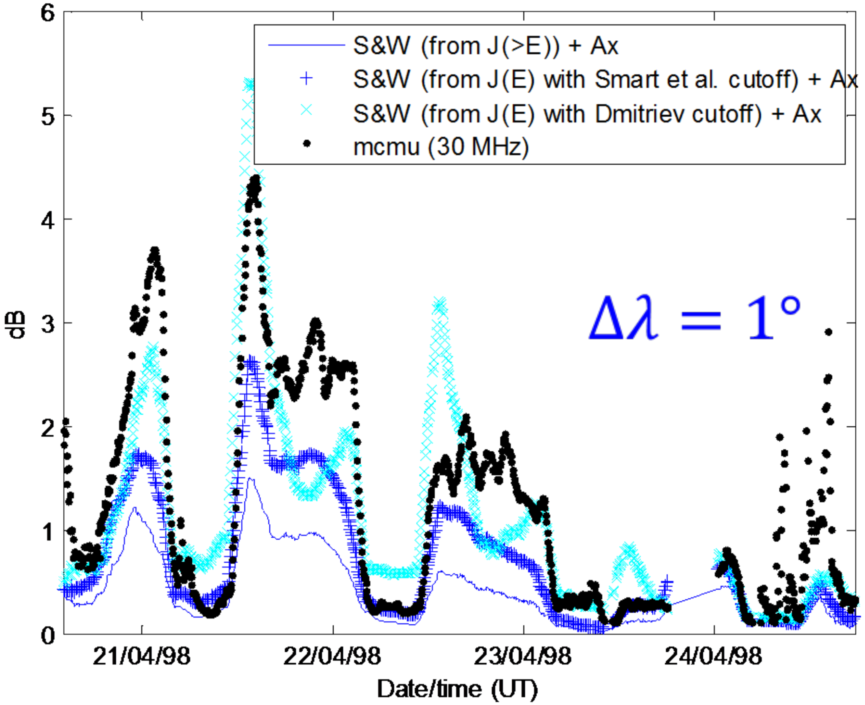
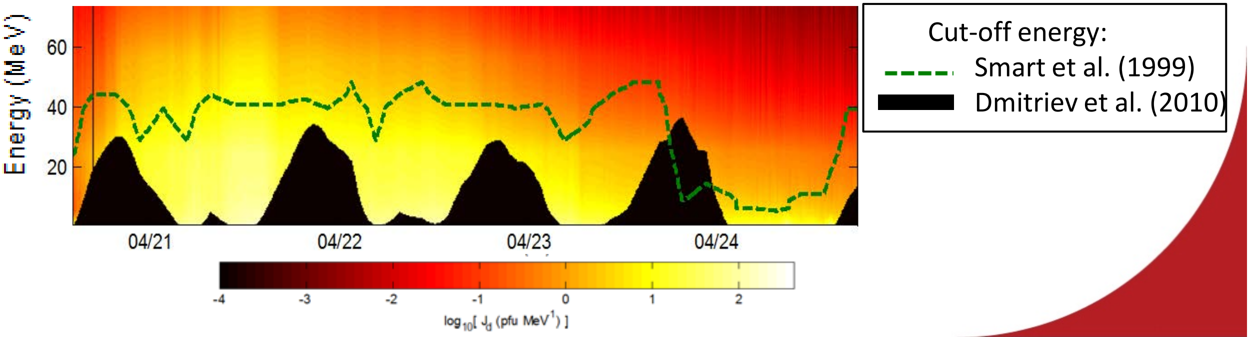


- The Dmitriev cut-off model improves on Smart model but predicts a regular midday recovery that isn't always observed on riometers
- The Smart cut-off is improved by a 1-2° equatorward shift





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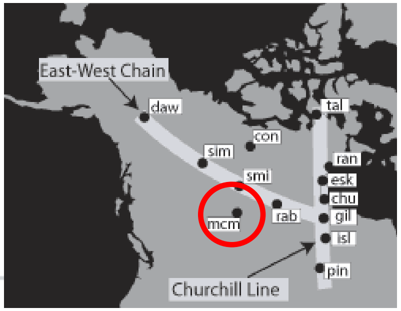

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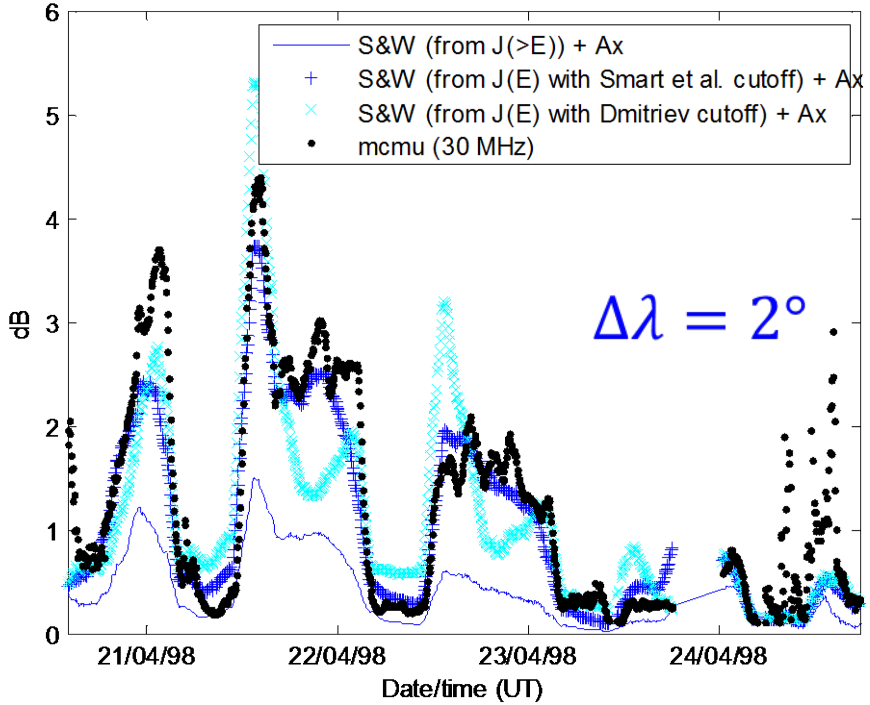
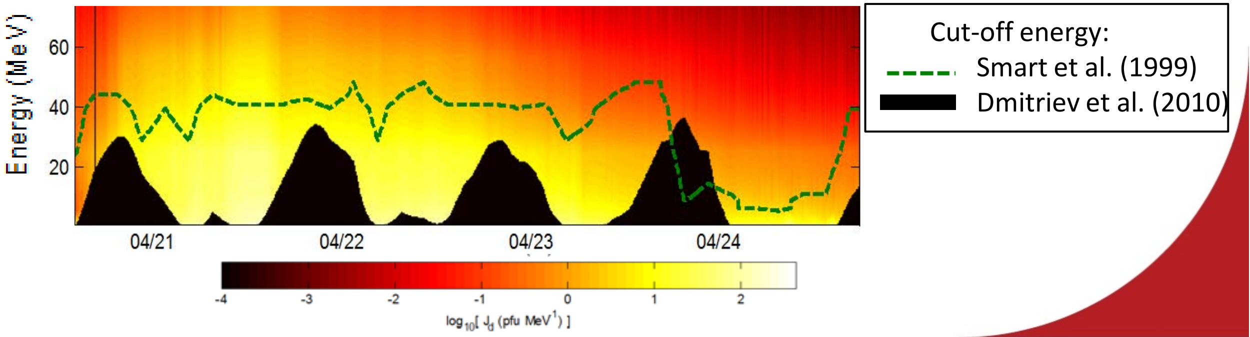
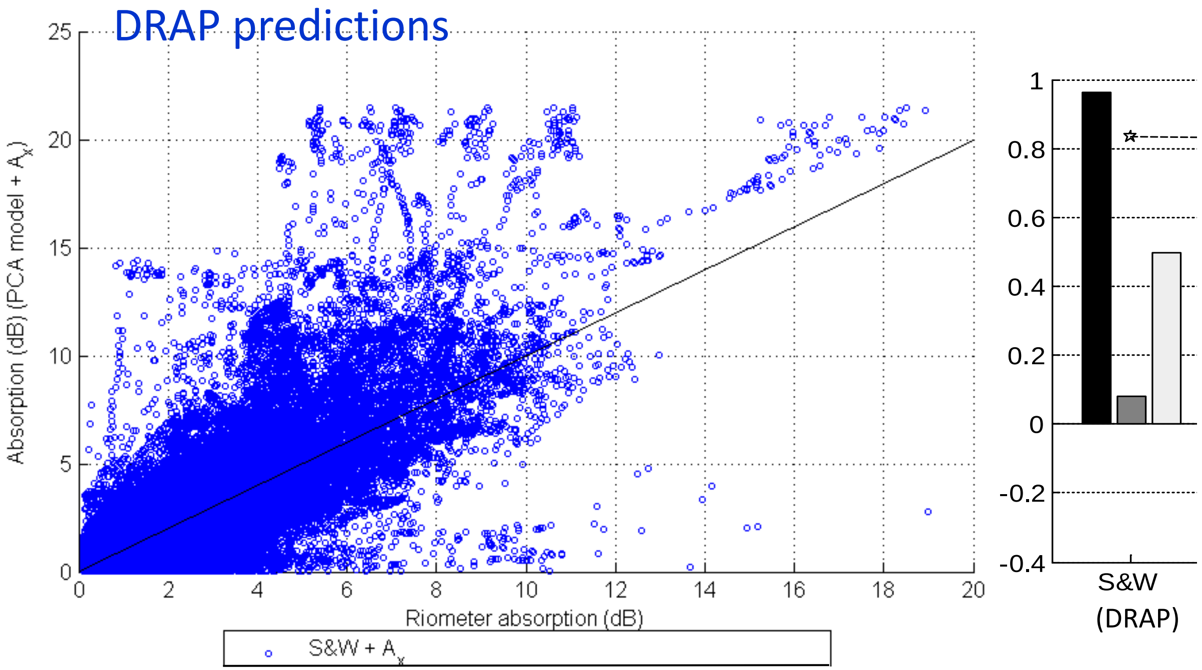


$\Delta\lambda = 2°$



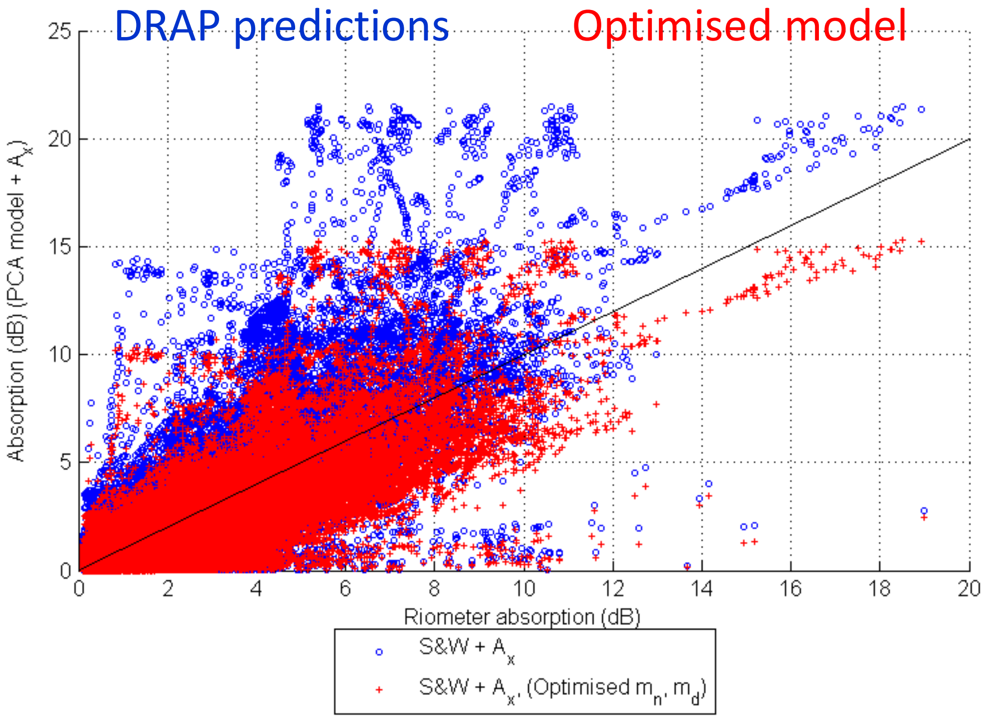
Cut-off energy:
Smart et al. (1999)
Dmitriev et al. (2010)

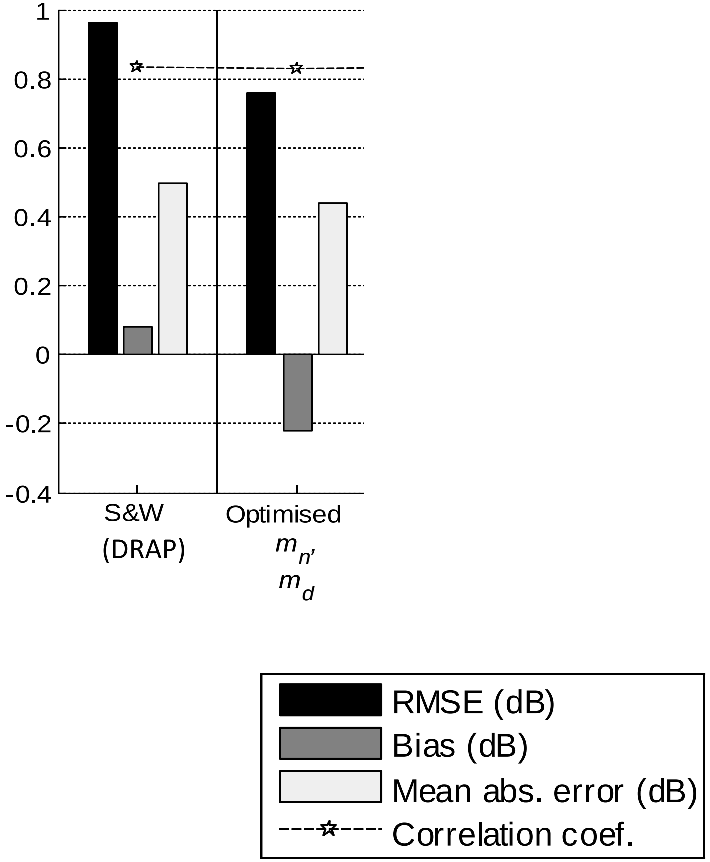
Model Optimisation



- DRAP model vs. riometer measurements
- (All SPEs 1995-2010, 14 riometers)

Model Optimisation



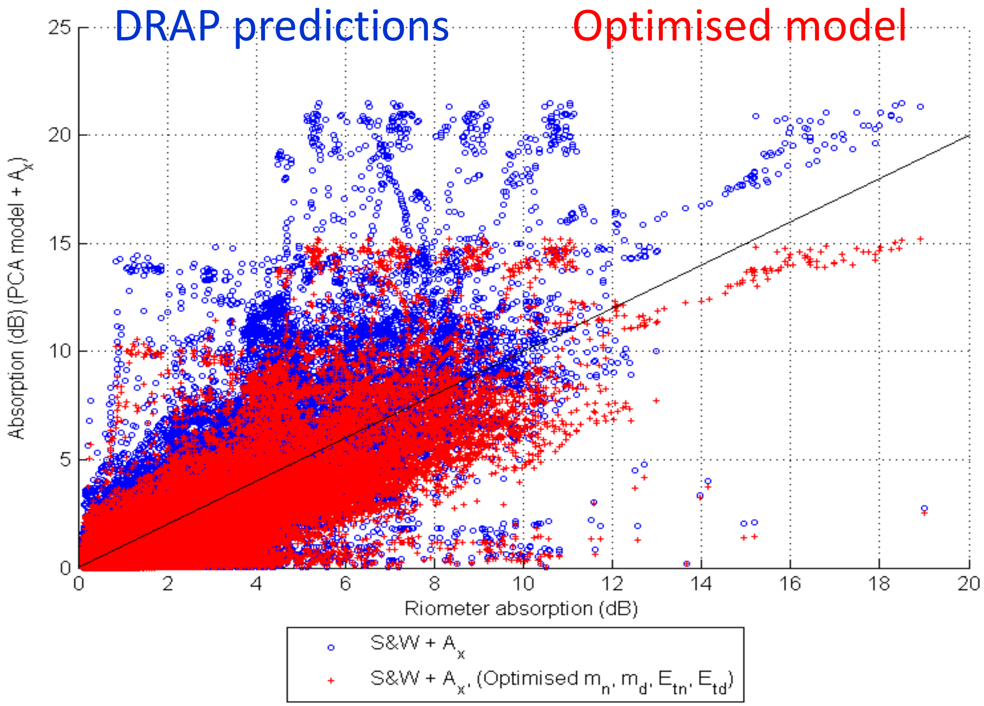


- Optimising ***m*** only (day and night)

$$A = \boldsymbol{m}\sqrt{J(>\boldsymbol{E_t})}$$

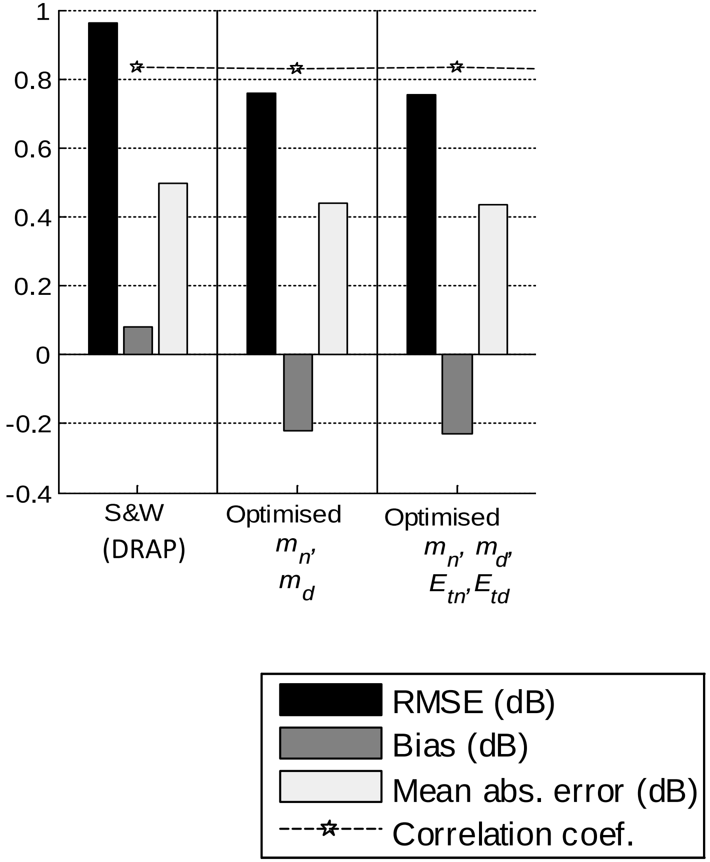
14 riometers, 94 SPEs

Model Optimisation



DRAP predictions

Optimised model

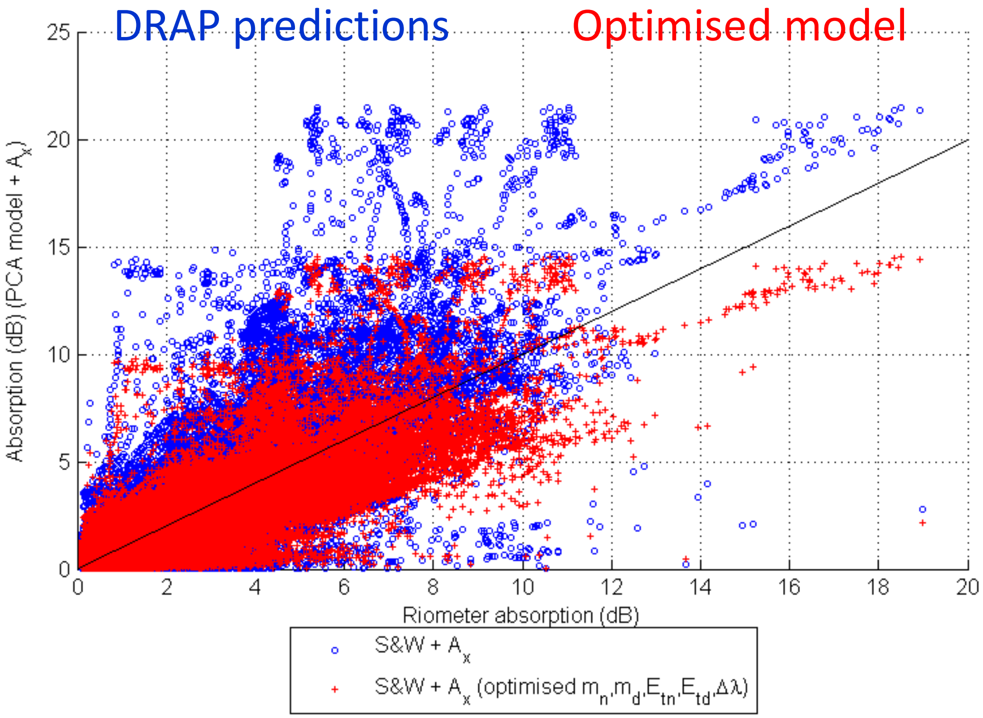


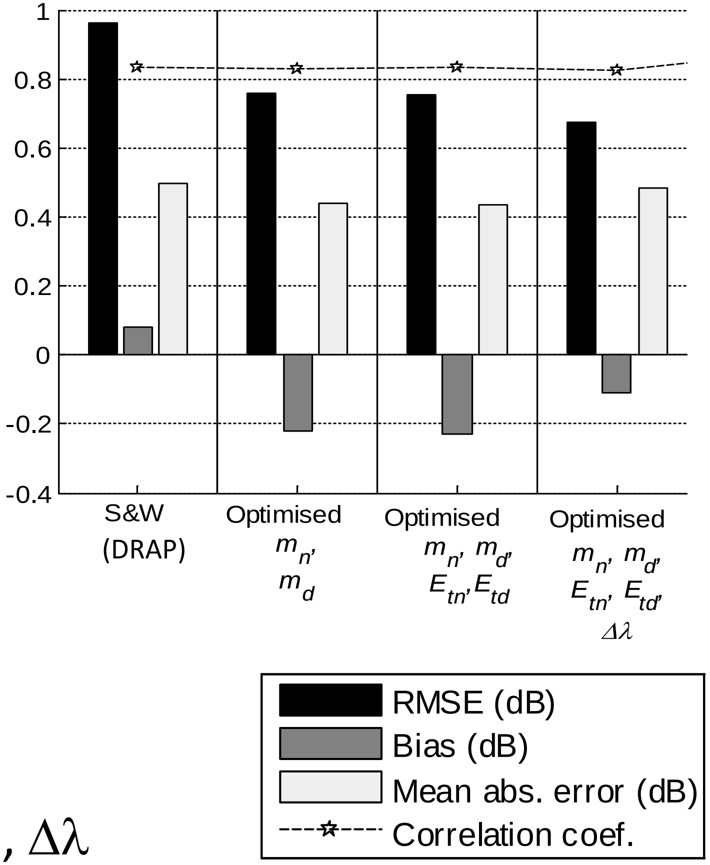
- Optimising ***m*** and $\boldsymbol{E_t}$ (day and night)

$$A = \boldsymbol{m}\sqrt{J(>\boldsymbol{E}_t)}$$

14 riometers, 94 SPEs

Model Optimisation

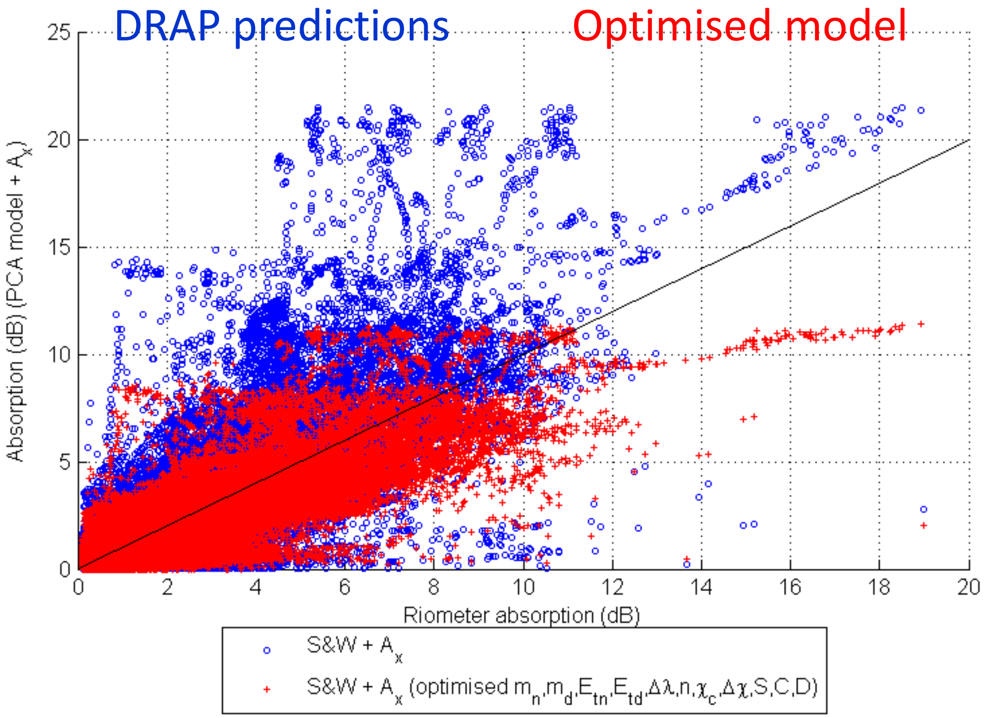


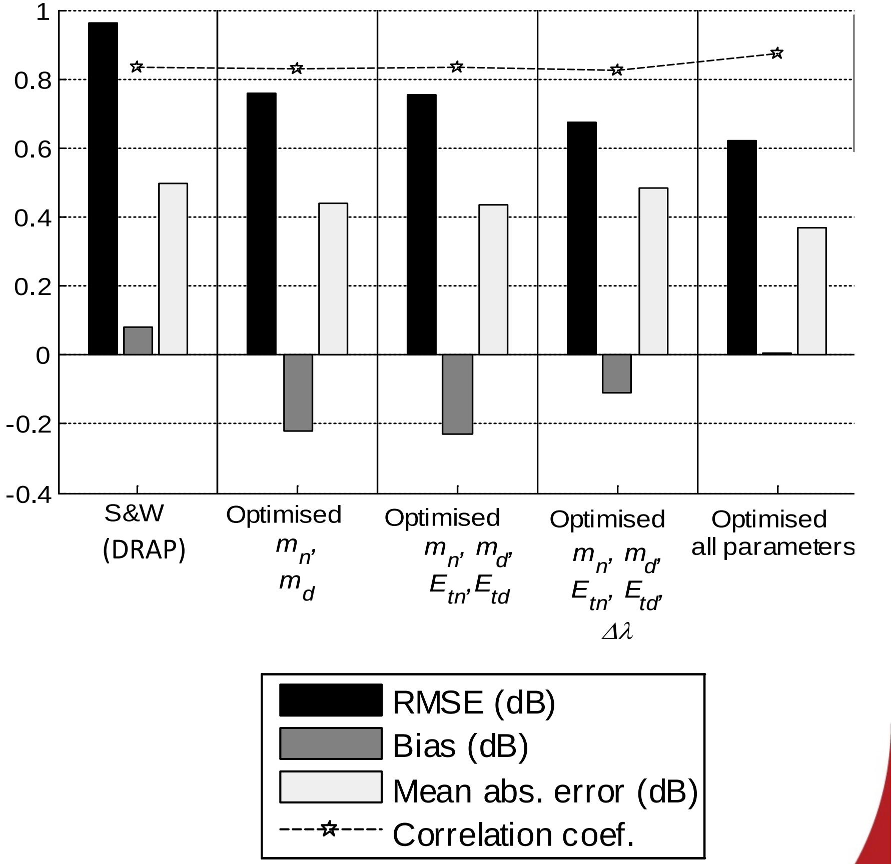


- Optimising ***m*** and ***E_t*** (day and night)
- Also optimising rigidity cut-off latitude, $\Delta\lambda$

14 riometers, 94 SPEs

Model Optimisation





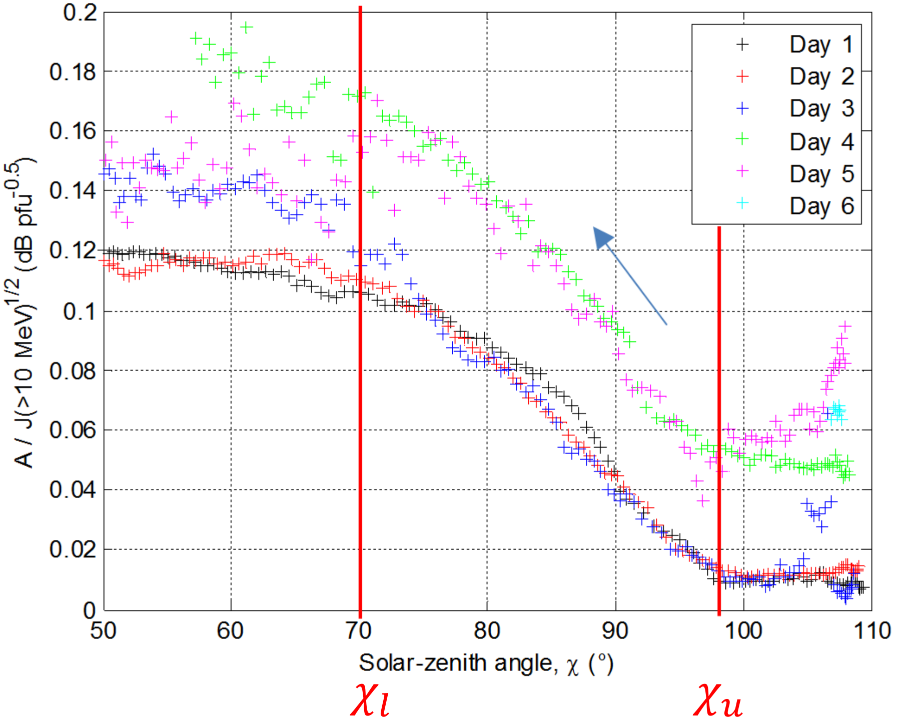
14 riometers, 94 SPEs

- Also optimising
  - Day/night zenith angle thresholds
  - Exponent n in $A = m\, J^n(> E_t)$.   *($n \approx 0.5$)*
  - Additional functions of MLT and season

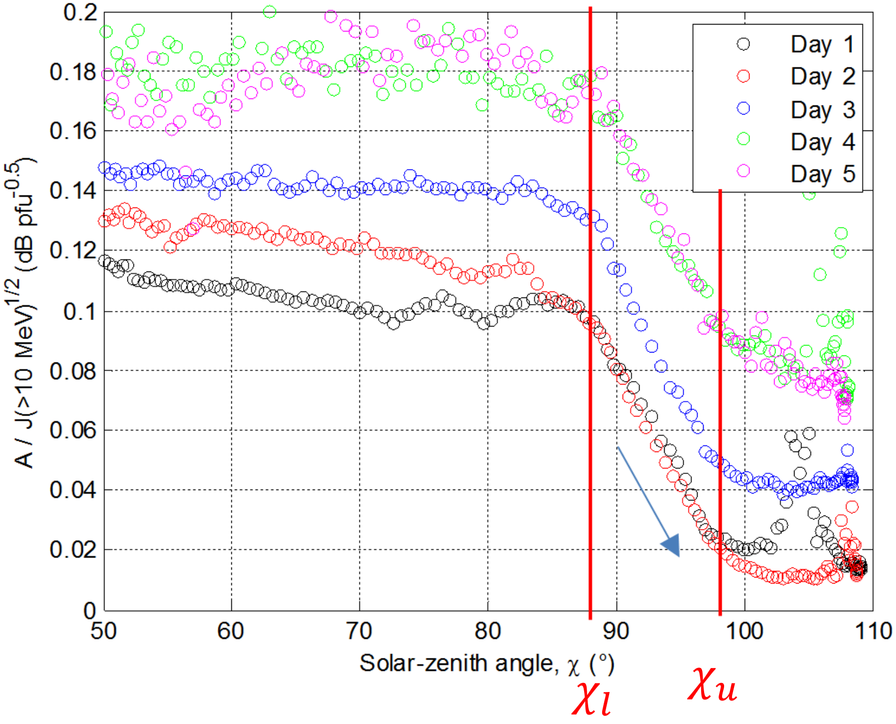
Optimising the Dawn/Dusk Response

$$m = A/\sqrt{J(>10\ MeV)}$$

Dawn



Dusk

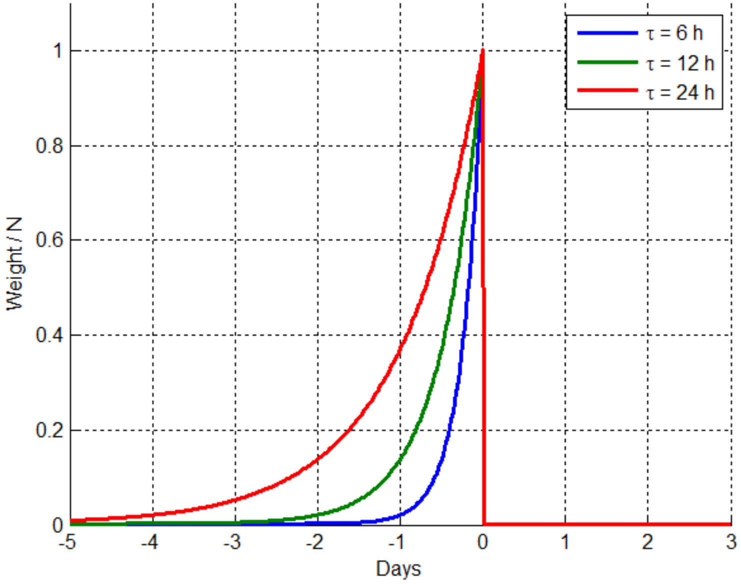


SPE commencing 21 April 2002. Fort Churchill riometer

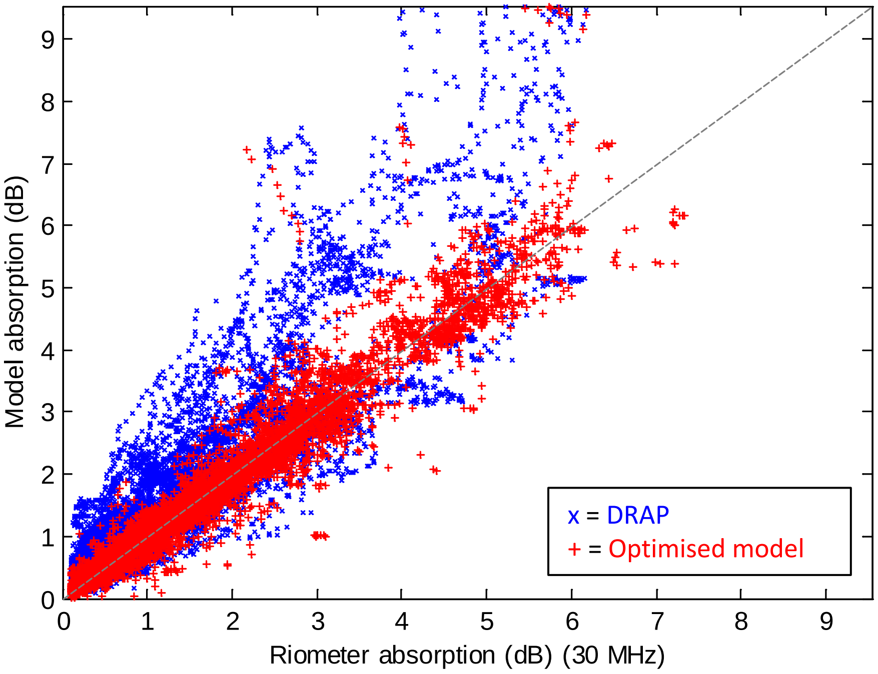
- Approx. linear dependence on solar-zenith angle, χ, in the twilight zone
- Need to optimise χ thresholds separately for dawn and dusk
- Note m varies from day to day

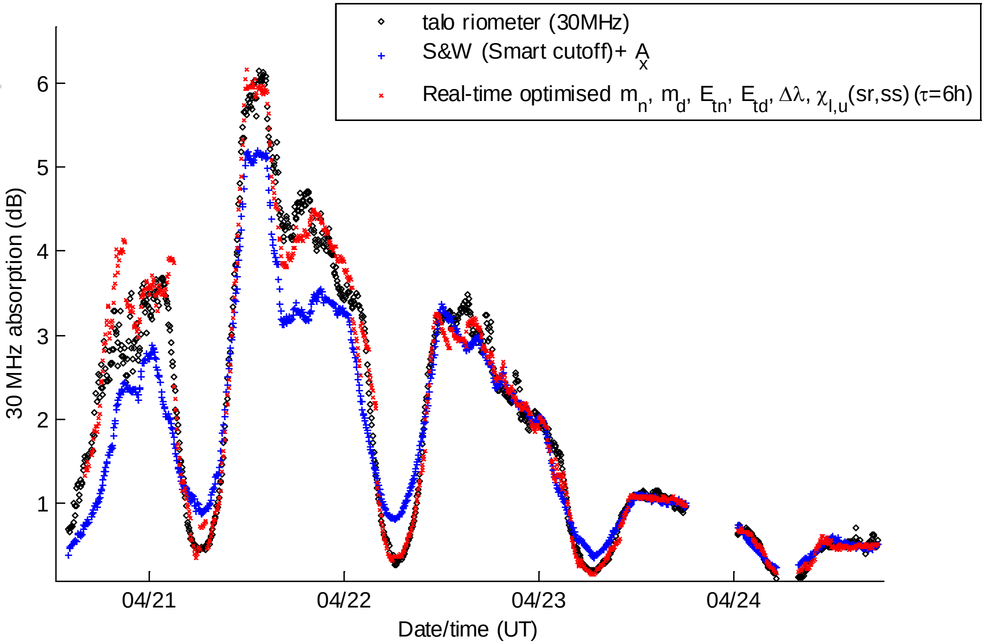
Age-weighting the optimisation

- Weight regression based on age of measurements
  - Exponential weighting with appropriate time constant , τ
    - 6 or 24 hours
- Update parameters every hour

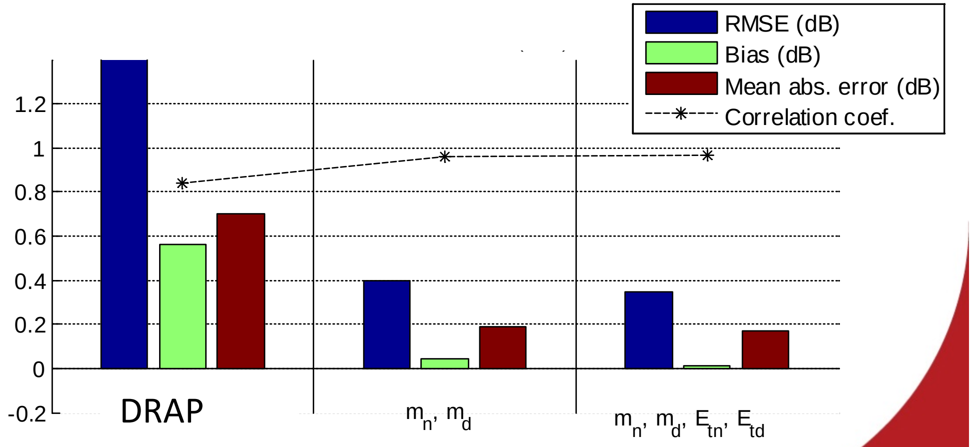


Single riometer optimisation (1-hourly updates)



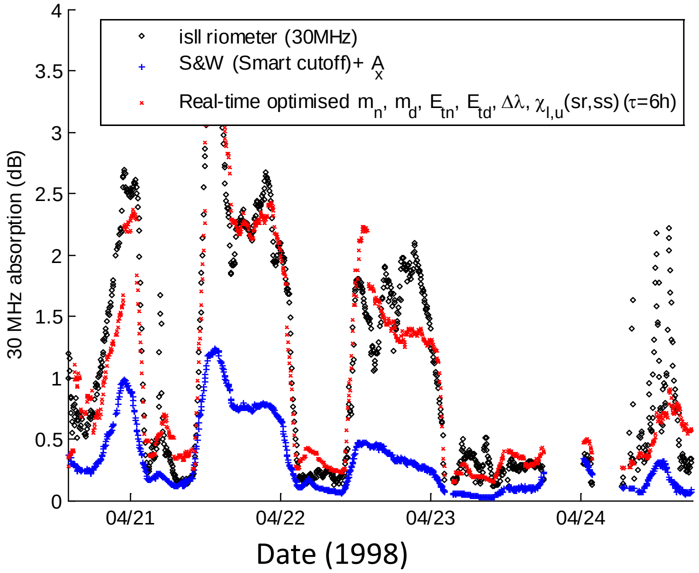


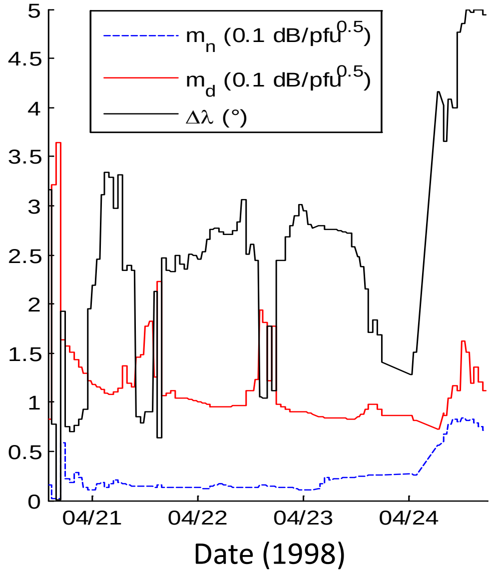
- Optimising at an individual riometer (Taloyoak) produces close fit to measurements
  - up to 1-hour ahead

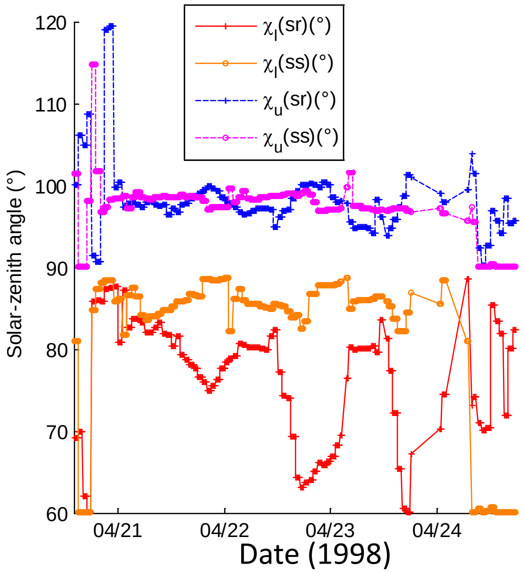


(Based on 13 large SPEs)

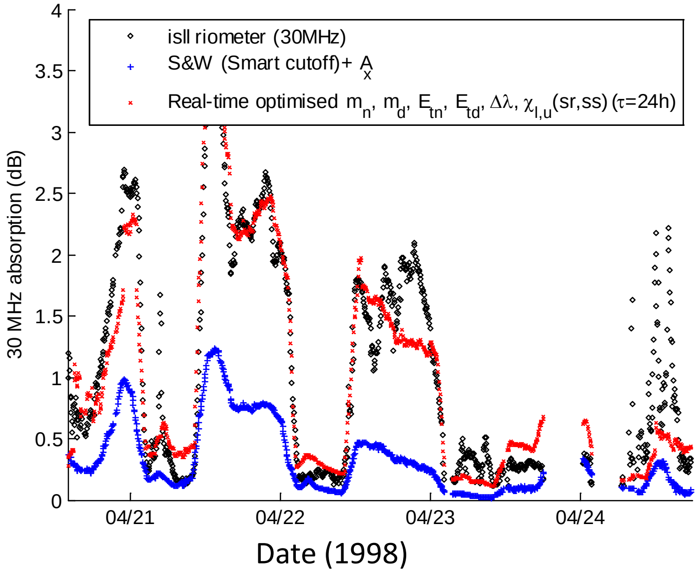
Optimised parameters: τ = 6h

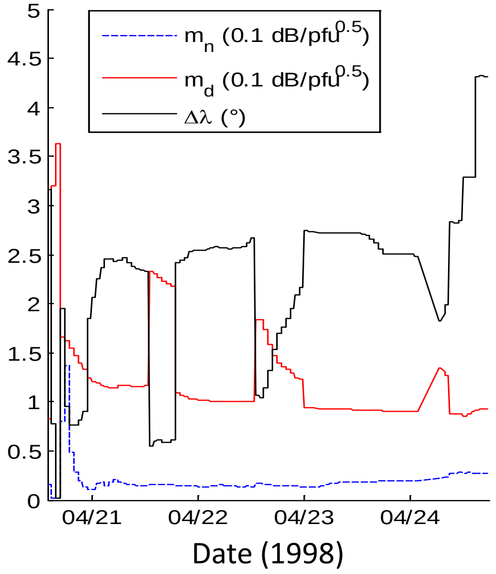


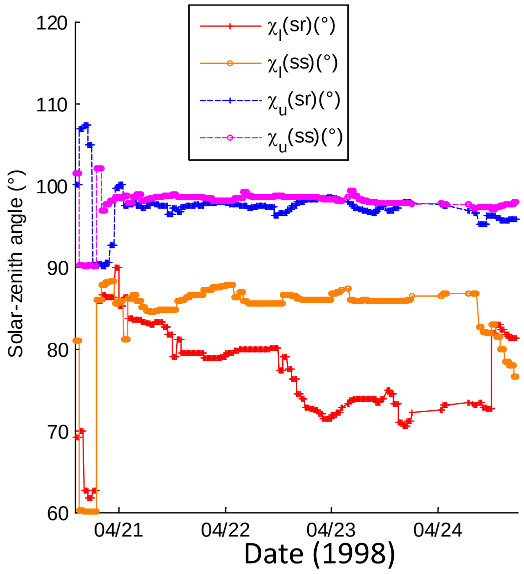




Optimised parameters: $\tau = 24$h

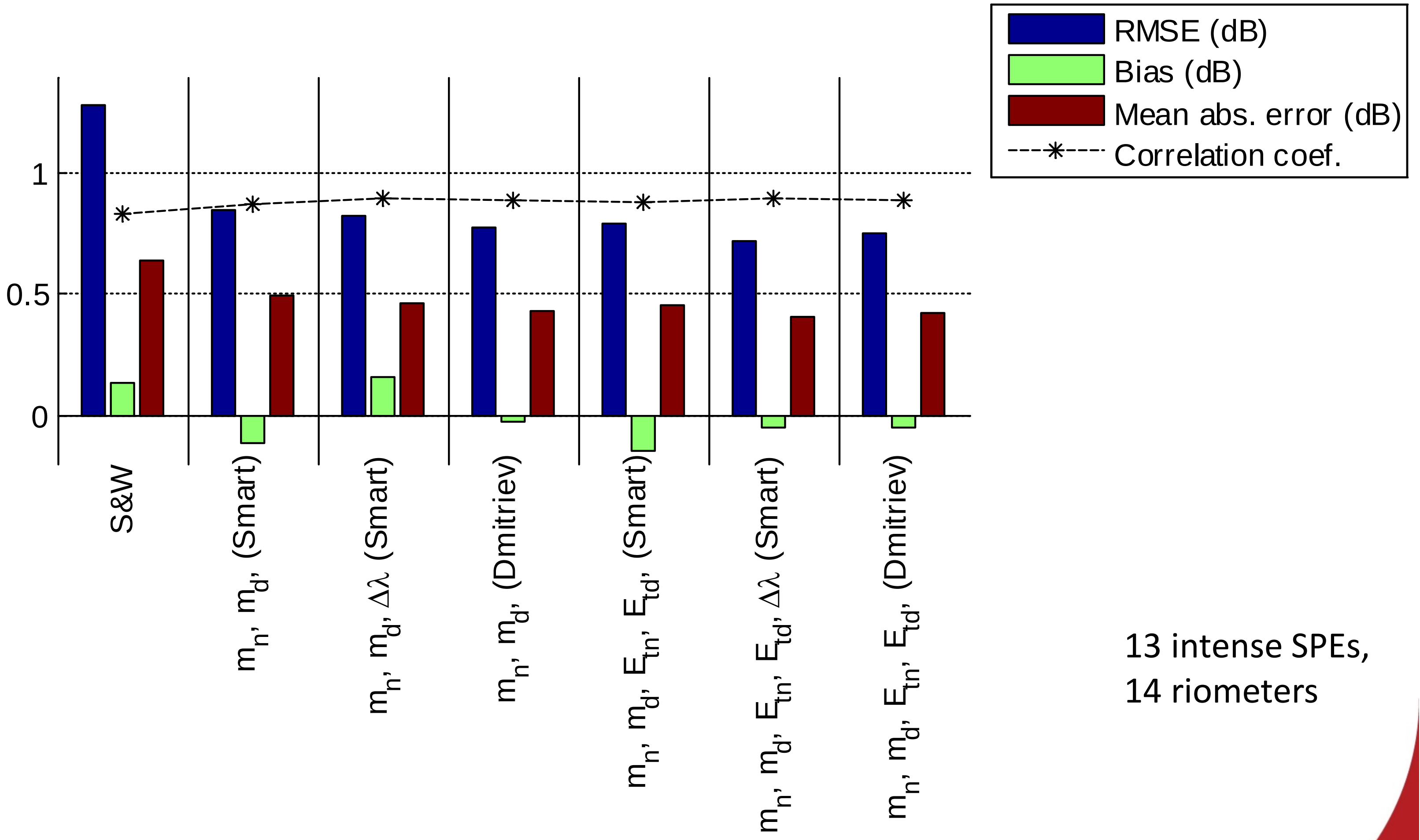






14-riometer optimisation: τ = 24h

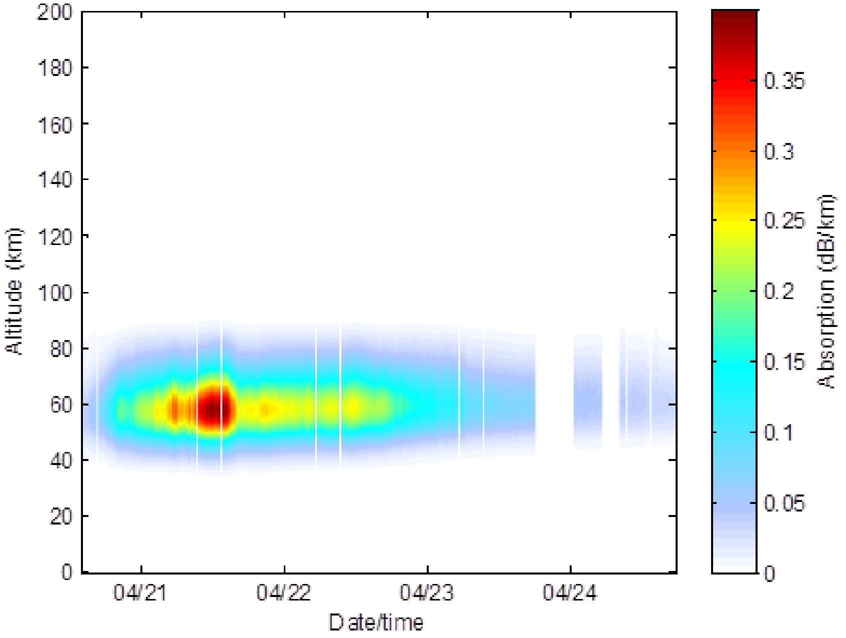
(1-hourly updates)



13 intense SPEs,
14 riometers

Type 2 PCA model (Full Profile model)

- Ionisation N_e determined from the ionisation rate and the effective recombination rate
- Effective recombination rate
  $$= \alpha_{eff}\ {N_e}^2$$
  - Large day/night variation in D region
- Model incorporates NRL MSISE-00 profiles of neutral density and electron temperatures



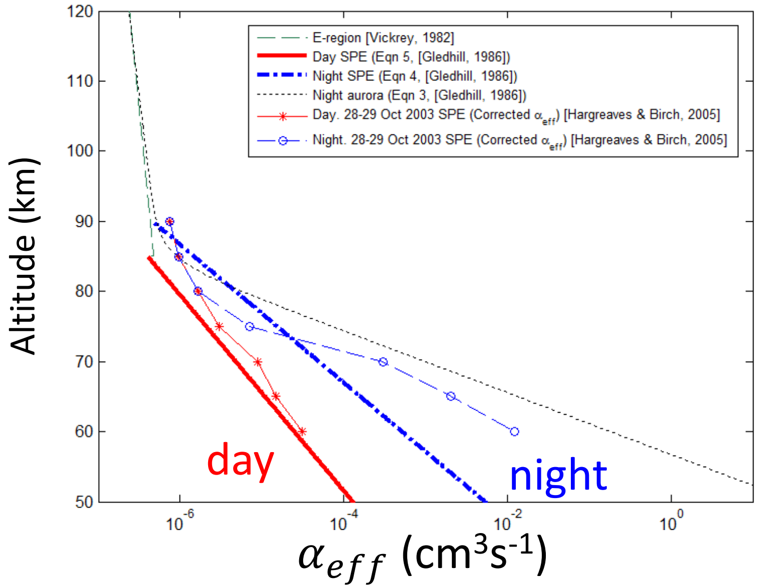
Specific absorption profiles, April 1998

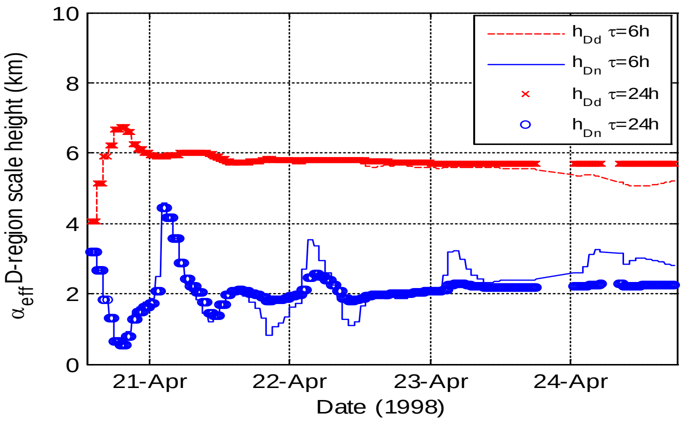
Type 2 PCA model: Optimisation

- Optimise the scale heights of the effective recombination coefficient, $\alpha_{eff}(z)$
  - Separately for day and night
  - Levenberg-Marquart non-linear least squares method

	h_{Dd} , h_{Dn} from (Gledhill 1986)	Optimised h_{Dd}, h_{Dn}
h_{Dn} (km)	4.27	3.18
h_{Dd} (km)	6.06	4.04
RMSE (dB)	2.17	0.75
Reduction in RMSE (%)	-	65.7
Bias (dB)	0.89	-0.22
Mean abs. error (dB)	0.92	0.42
Correlation coefficient	0.77	0.75

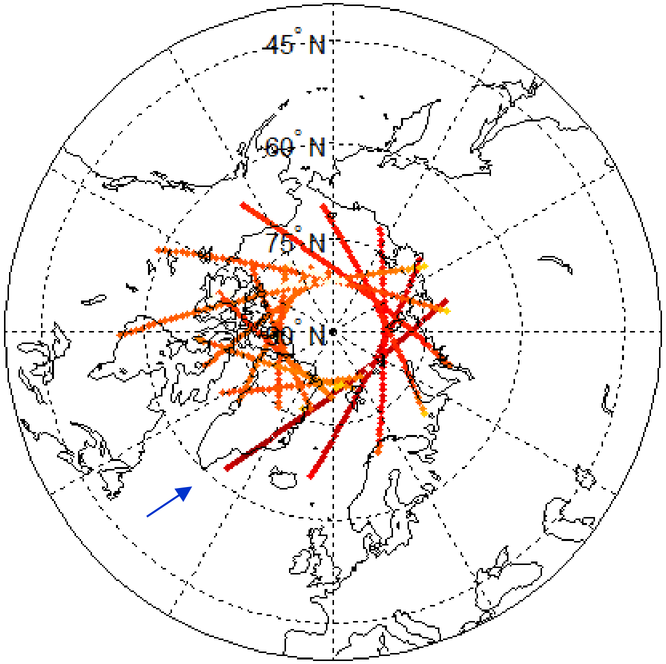
Initial and optimised parameters for Taloyoak (all 94 SPEs)



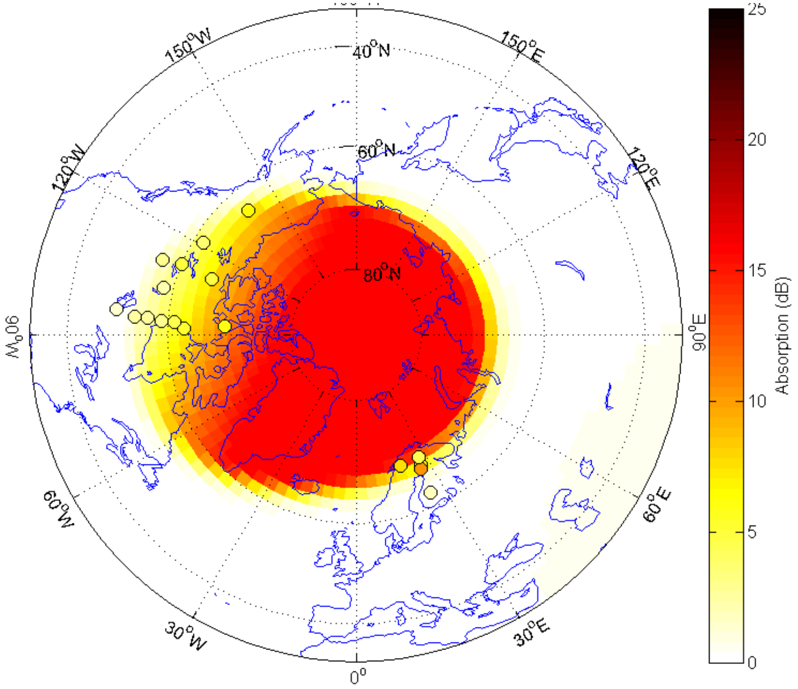


Incorporating POES measurements

POESDRAP : 15-Jul-2000 - 15-Jul-2000 12:00:00

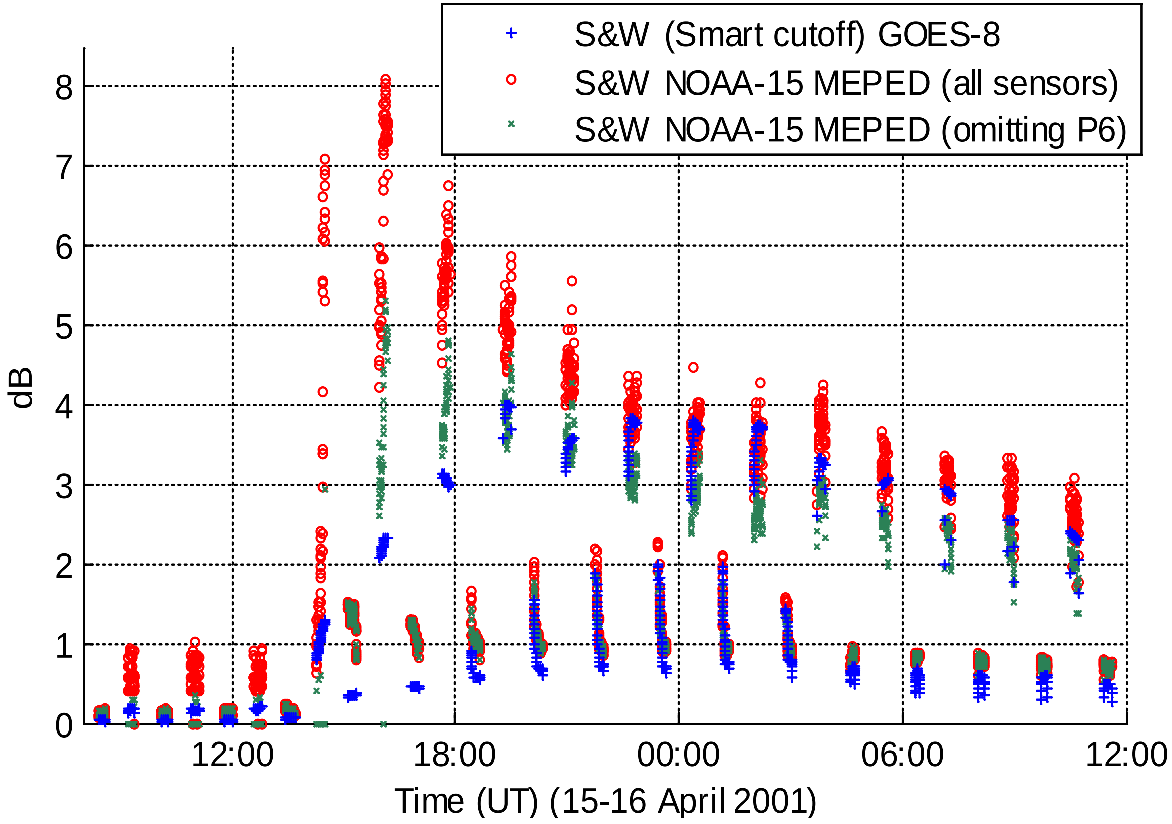


GOES (DRAP) 15 July 2000, 08:00



- POES (MEPED instrument) provides independent measurement of proton flux spectrum J(>E) and rigidity cut-offs

POES vs GOES PCA prediction

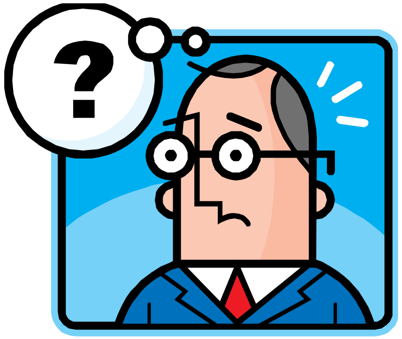


L>6 only

- POES absorption prediction at foot of field line (NOAA 15 satellite) closely matches that using GOES satellite except in first 6 hours of SPE
  - P6 instrument (>6.9 MeV protons) contaminated by relativistic electrons

Conclusions

- Real-time optimisation of PCA models
  - Non-linear age-weighted regression to riometer measurements
  - Reduces RMSE to < 1 dB, and bias to within +/-0.2 dB
  - Type 1 model:
    - Optimise linear scaling factors, energy thresholds, rigidity cutoff latitude
    - Optimise χ boundaries of twilight region separately for dawn and dusk
  - Type 2 model:
    - Optimise scale height of α_{eff} in D region (day and night)
- Assimilating POES measurements
  - Directly measure rigidity cut-off boundaries
  - Proton flux measurements contaminated by relativistic electrons on P6 channel



Any Questions?