Evaluation of Simulated Irradiances from the Integrated Forecast Scheme with Aircraft Observations

Leipzig Institute for Meteorology
University of Leipzig

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André Ehrlich, and Manfred Wendisch

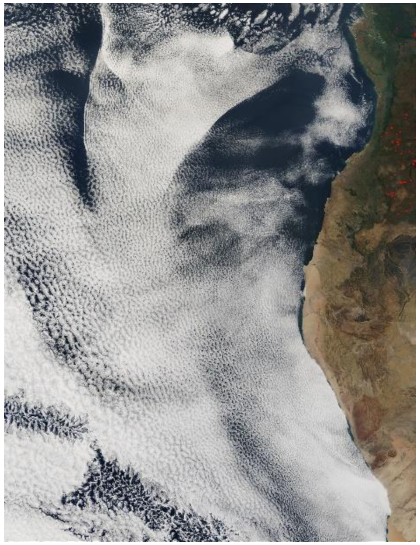
NAWDEX Workshop Toulouse
26 - 28 March 2019

Motivation

European Center for Medium Range Weather Forecast

Operates Integrated Forecast Scheme (IFS)

- Known deficiencies
  - Mixed-Phase clouds in could air outbreaks



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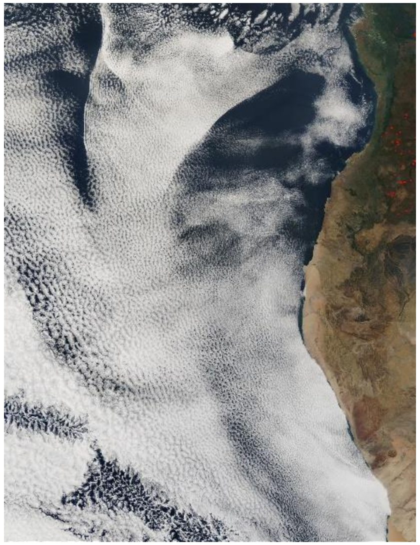

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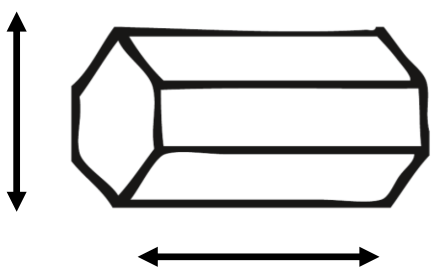
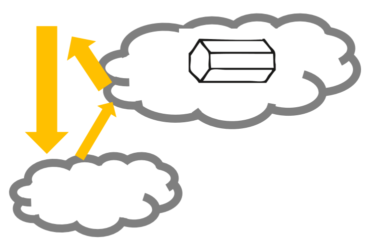
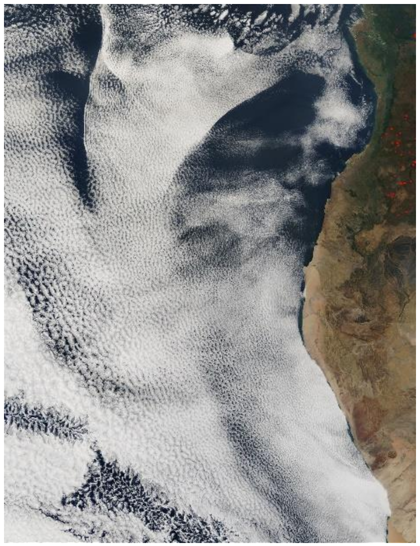
  - Ice crystal shape parameterization







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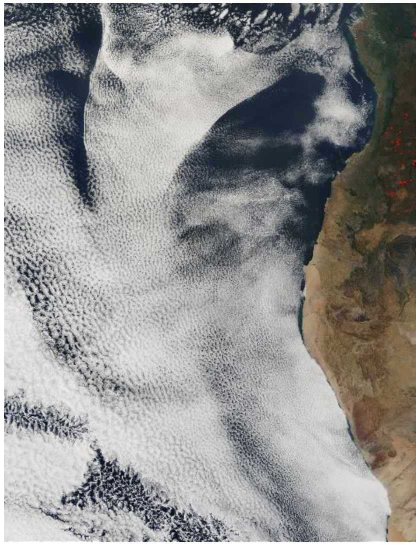
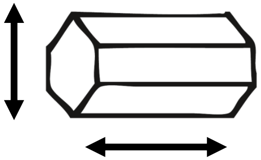
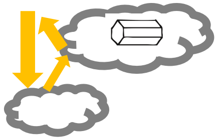


Validation of:

- Cloud representation in IFS analysis data
- Cloud optical parametrization





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Motivation

European Center for Medium Range Weather Forecast

Operates Integrated Forecast Scheme (IFS)

Modular

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ECMWF

IFS

Data Assimilation

Ocean Model

Dynamic and Numerical Processes

Physical Processes
- **Radiation**
- Turbulence
- Clouds / Precipitation
- Aerosols

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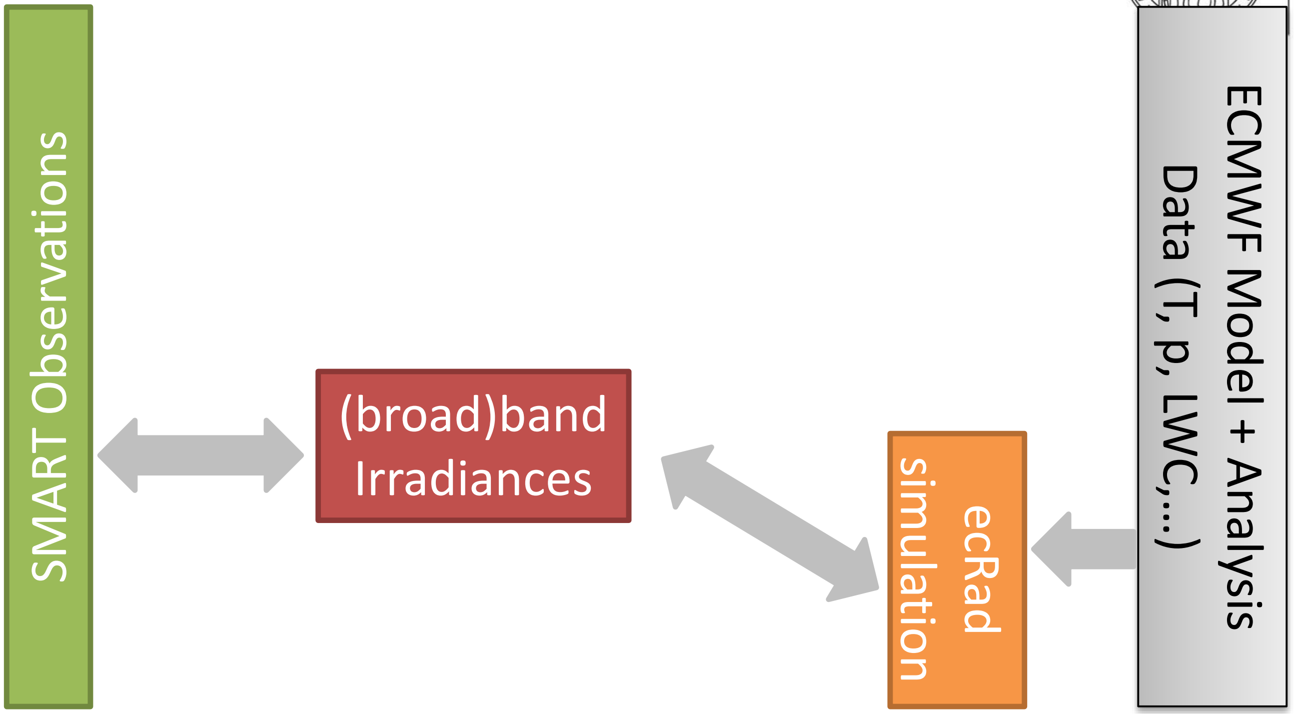
Motivation – Model evaluation



- Run radiation scheme separatly
- Use ECMWF OpenIFS

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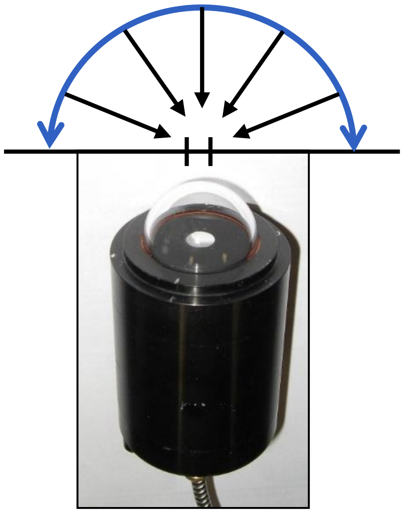
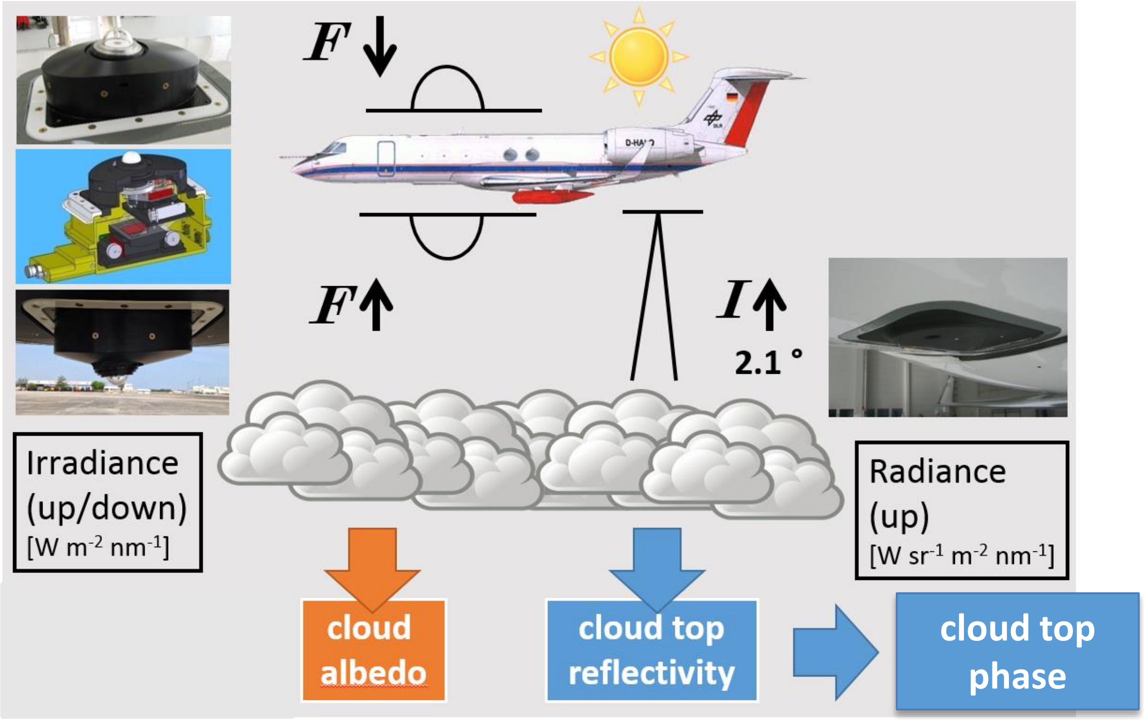
Instrumentation - SMART

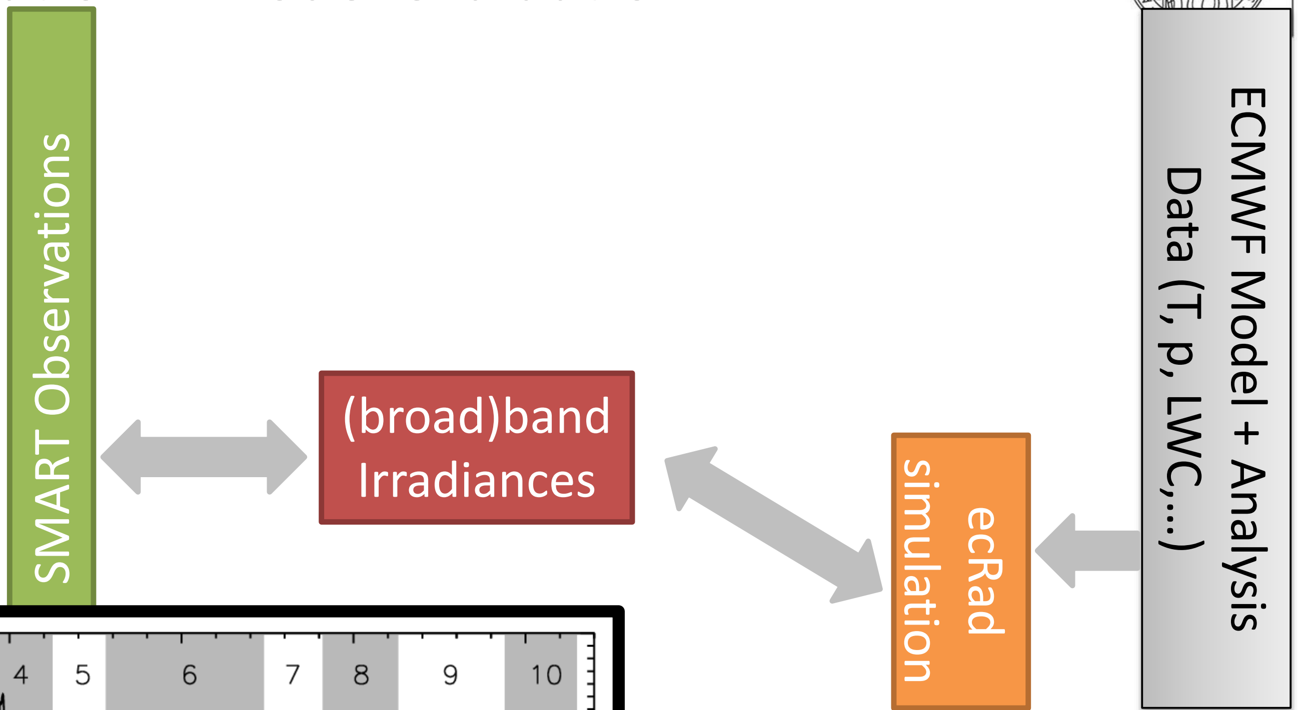


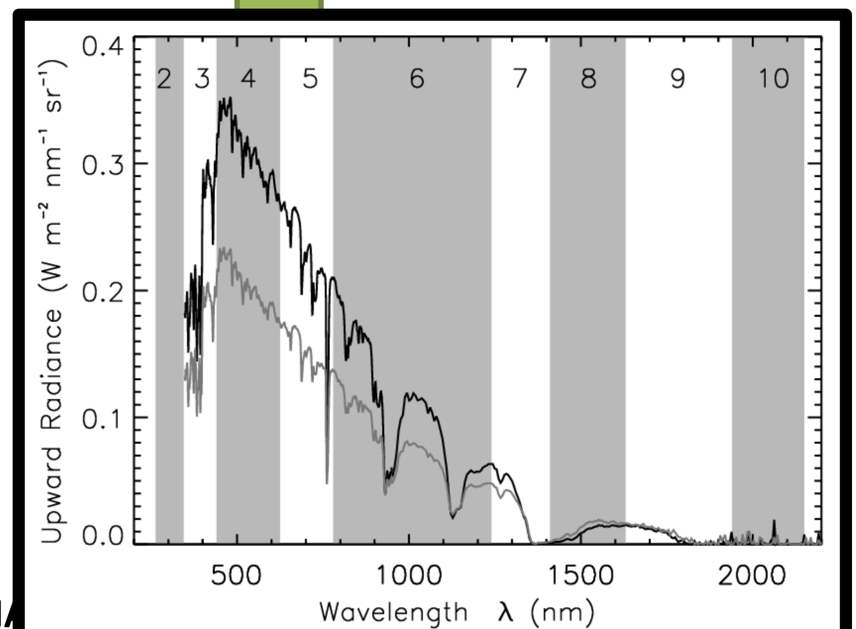


- Zeiss grating spectrometers
- **Temporal resolution:** 2 – 5 Hz
- **Wavelength range**: 300 – 2200 nm
- **Spectral resolution**: 2 – 16 nm FWHM

[1] **Wendisch, M. et al.**, 2001

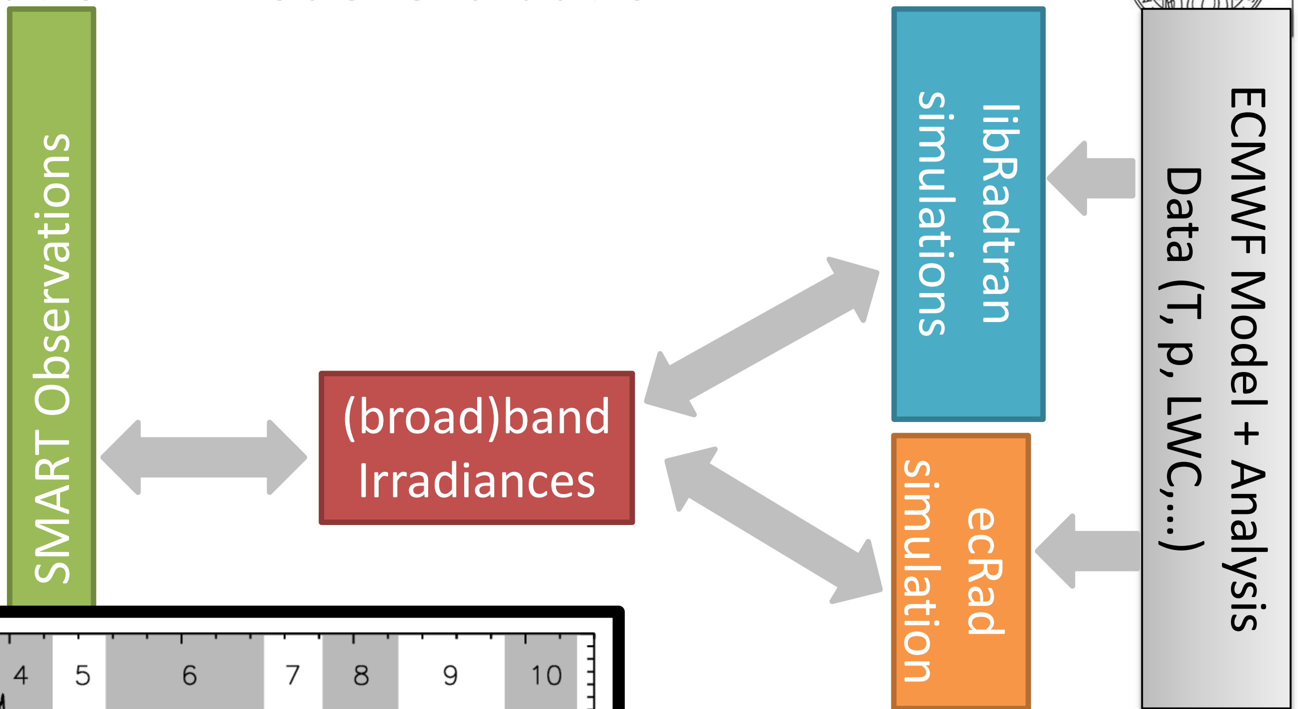
Motivation – Model evaluation

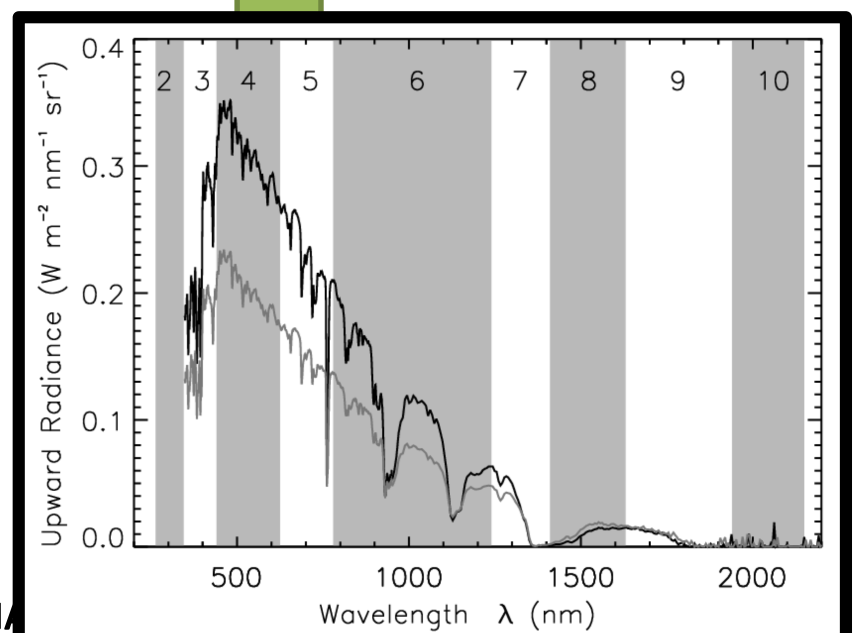




- Run radiation scheme separatly
- Use

Motivation – Model evaluation





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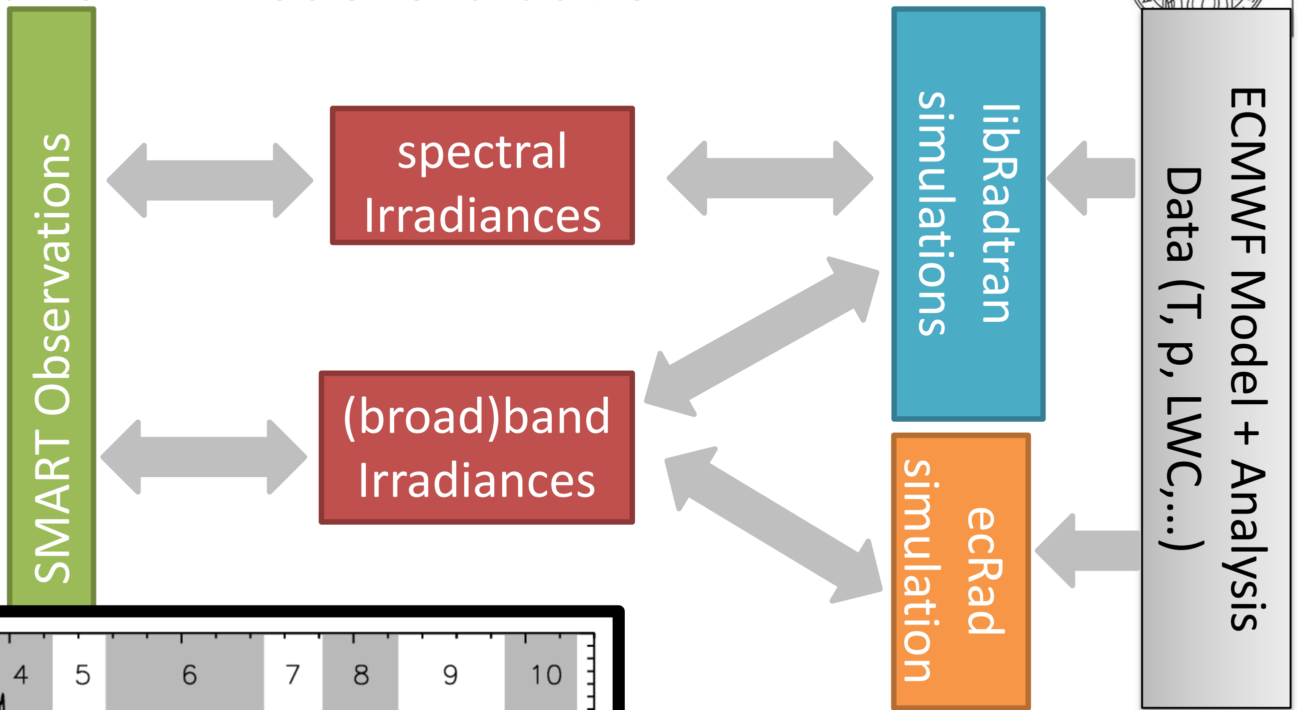
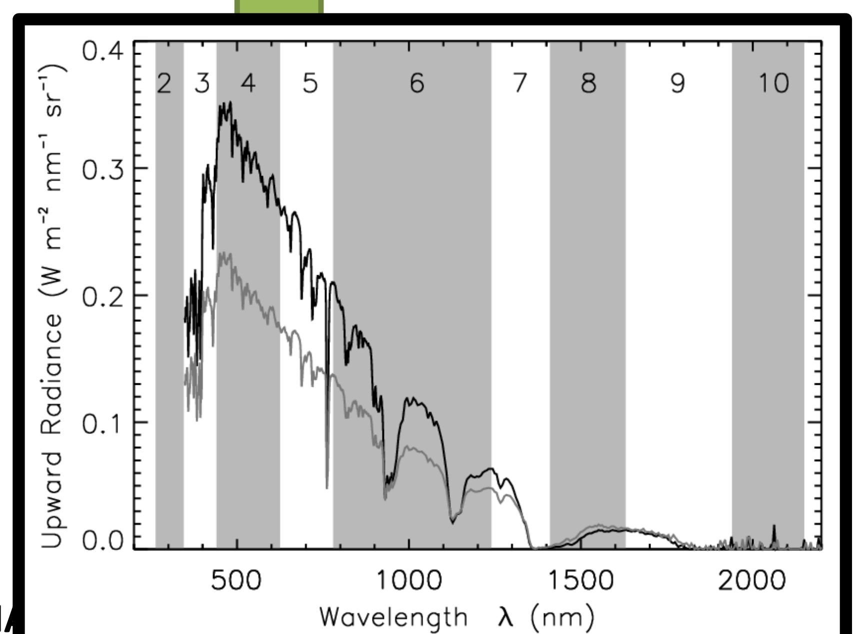
ECMWF Open IFS

libRadtran

Motivation – Model evaluation

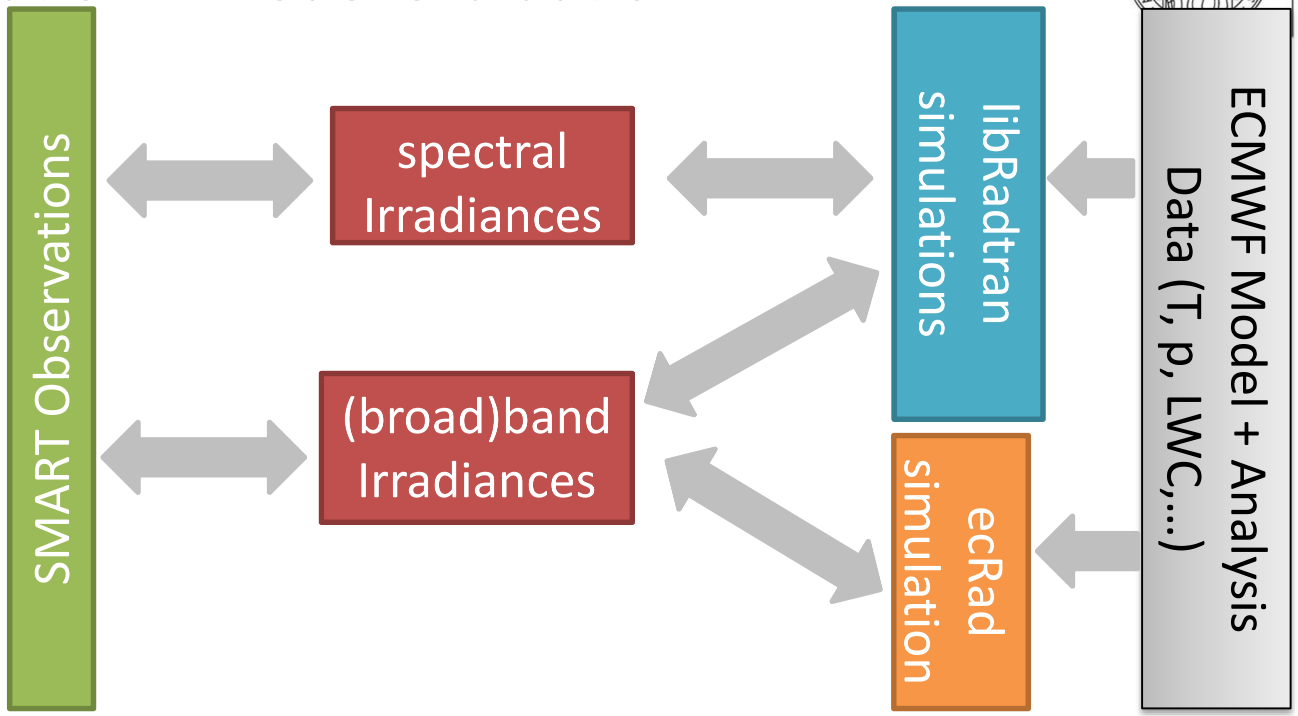




- Run radiation scheme separatly
- Use

NA

Motivation – Model evaluation



Observation	✓	libRadtran	✓	ecRad	➡	
Observation	✗	libRadtran	✓	ecRad	➡	Cloud Error
Observation	✓	libRadtran	✗	ecRad	➡	Radiation Scheme Error
Observation	✗	libRadtran	✗	ecRad	➡	?

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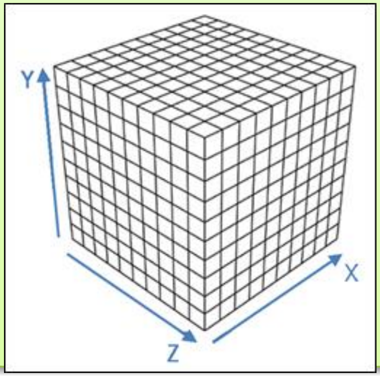
Model Set-Up 1st step: Data Along Flight Track

3D-Fields of Global Analysis Data

spatial resolution: 0.1°
temporal resolution: 1 h

parameters: T, Q, LWC, IWC, RWC, SWC, u, v, ω, ps, SLP, FCC, p, SKT



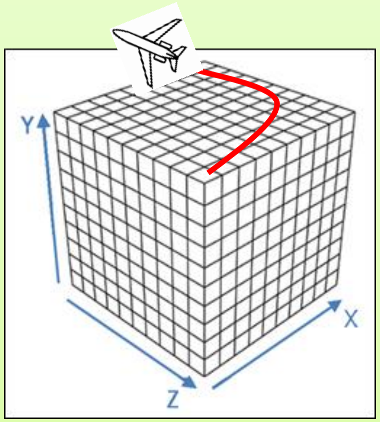
t = 2 s
linear temporal interpolation between hour files

interpolated spatial resolution

nearest neighbor

Vertical Columns along Flight Track

parameters: T, Q, LWC, IWC, RWC, SWC, u, v, ω, ps, SLP, FCC, p, SKT



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Model Set-Up 2nd step: Calculate Missing Input Parameters

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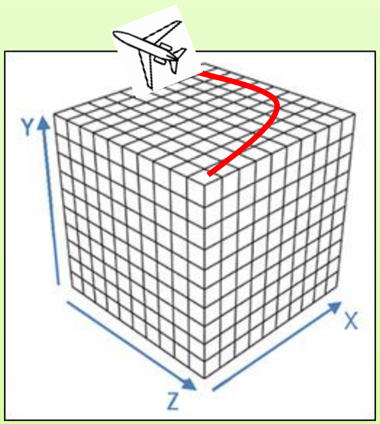
Vertical Columns along Flight Track

parameters: T, Q, LWC, IWC, RWC, SWC, u, v, ω, ps, SLP, FCC, p, SKT



Calculate r_{eff} for ice particles and droplets

ECRAD

input parameters:
SZA, p, T, Q, FCC, IWC, LWC, RWC, SWC, gas ratios, default parameter settings,
+
$\mathbf{r_{eff,liquid}}$
$\mathbf{r_{eff,ice}}$

output parameters:

- F_{up} / F_{dw}: sw/lw int. / spect. bands
- cloud cover

Model Set-Up 3rd Step: Calculate Missing Input Parameters / IFS Namelist

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Case Study - Flight 26.09.2016 ‘Karl’

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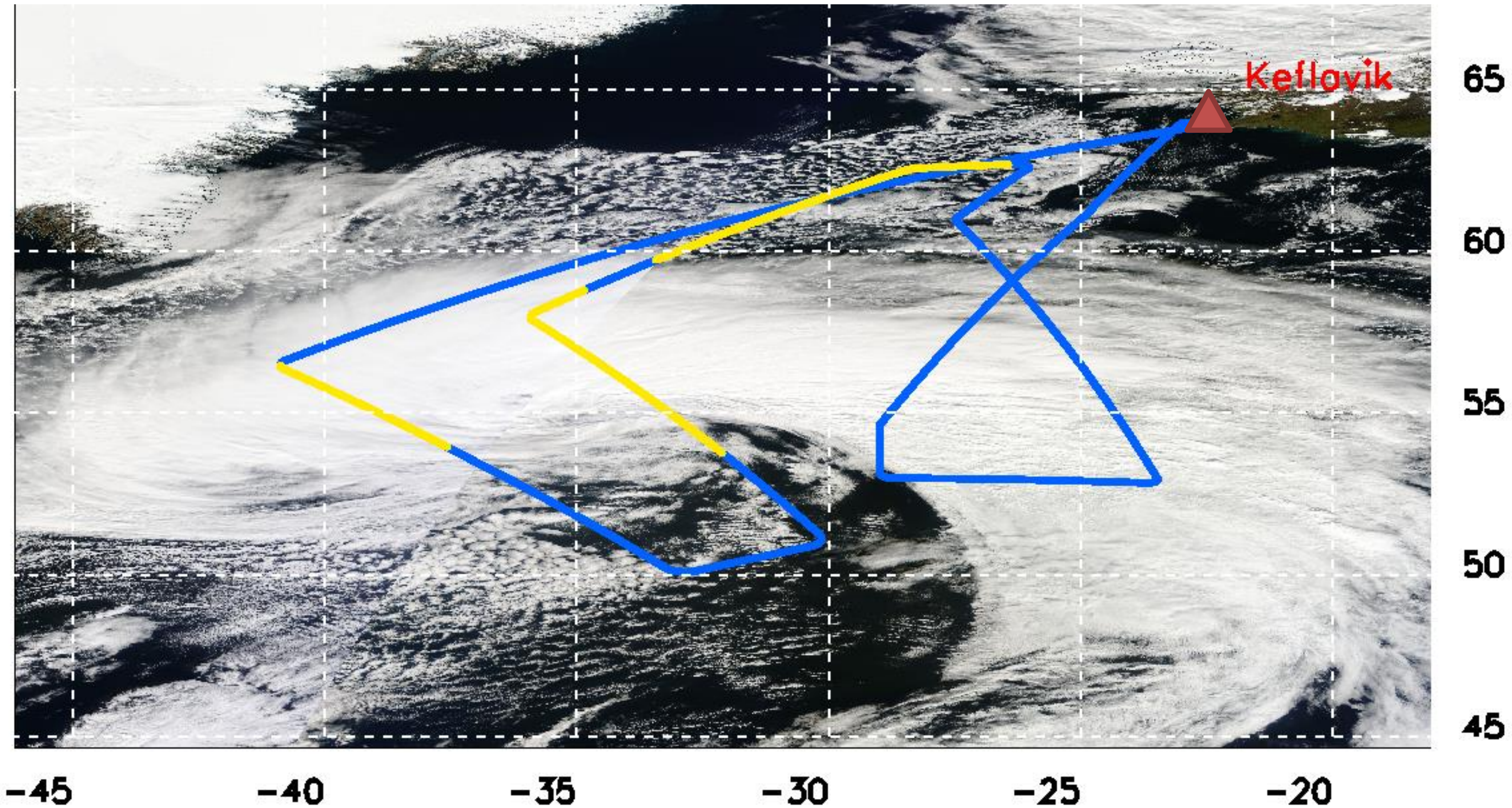

Modis Terra satellite image from 26.09.2016 of ‘Karl’ with entire flight track of HALO (blue) and selected cloud cases (yellow) .

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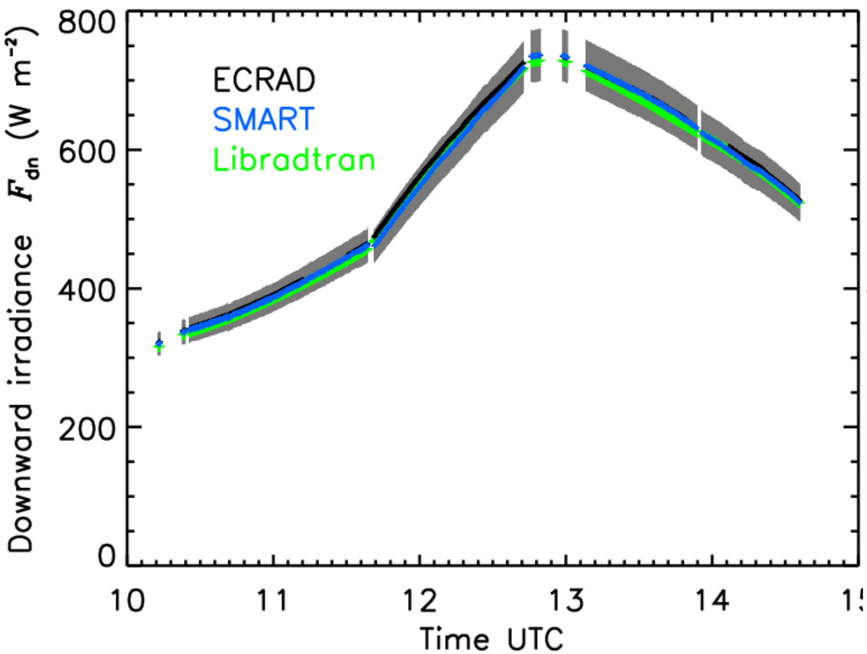
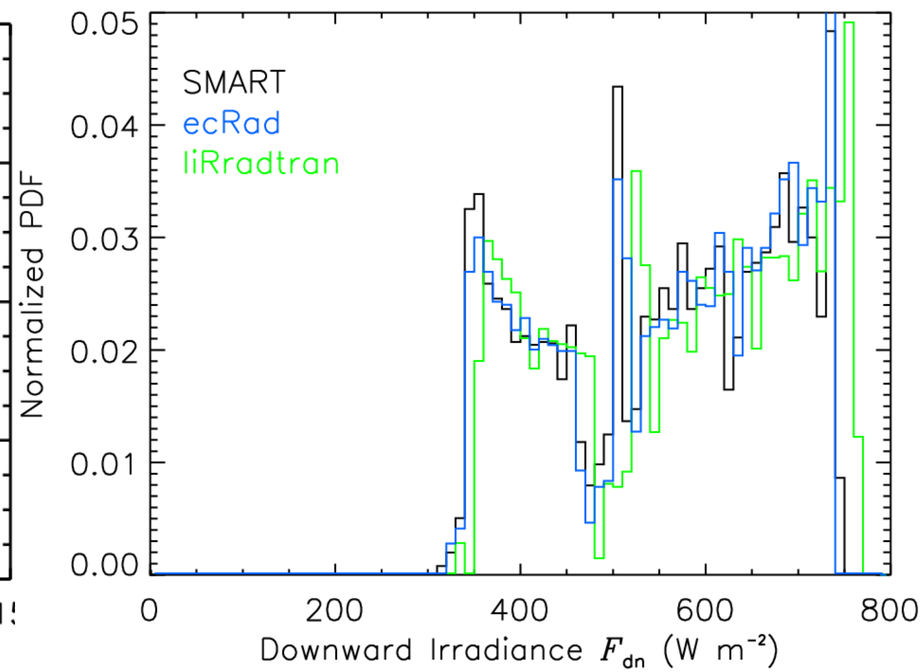
Case Study – Plausibility Check





- F_{dn} agrees for measurement and model
- Within SMART uncertainty of 5% (gray)
- Energy input in system is equal

- Two modes due to straight flight legs
- Influence of solar zenith angle
- Check incoming radiation

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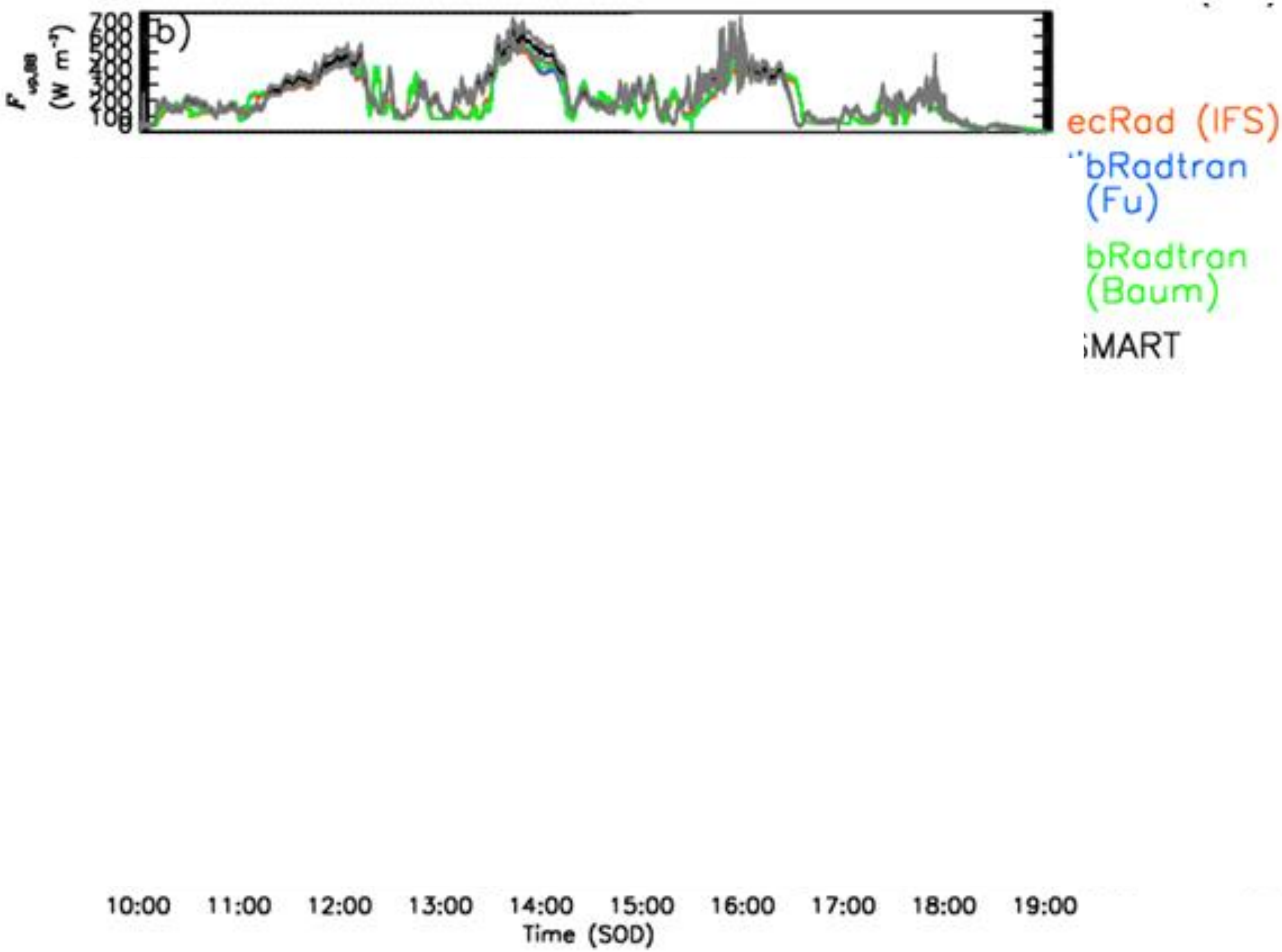
Case Study – time series



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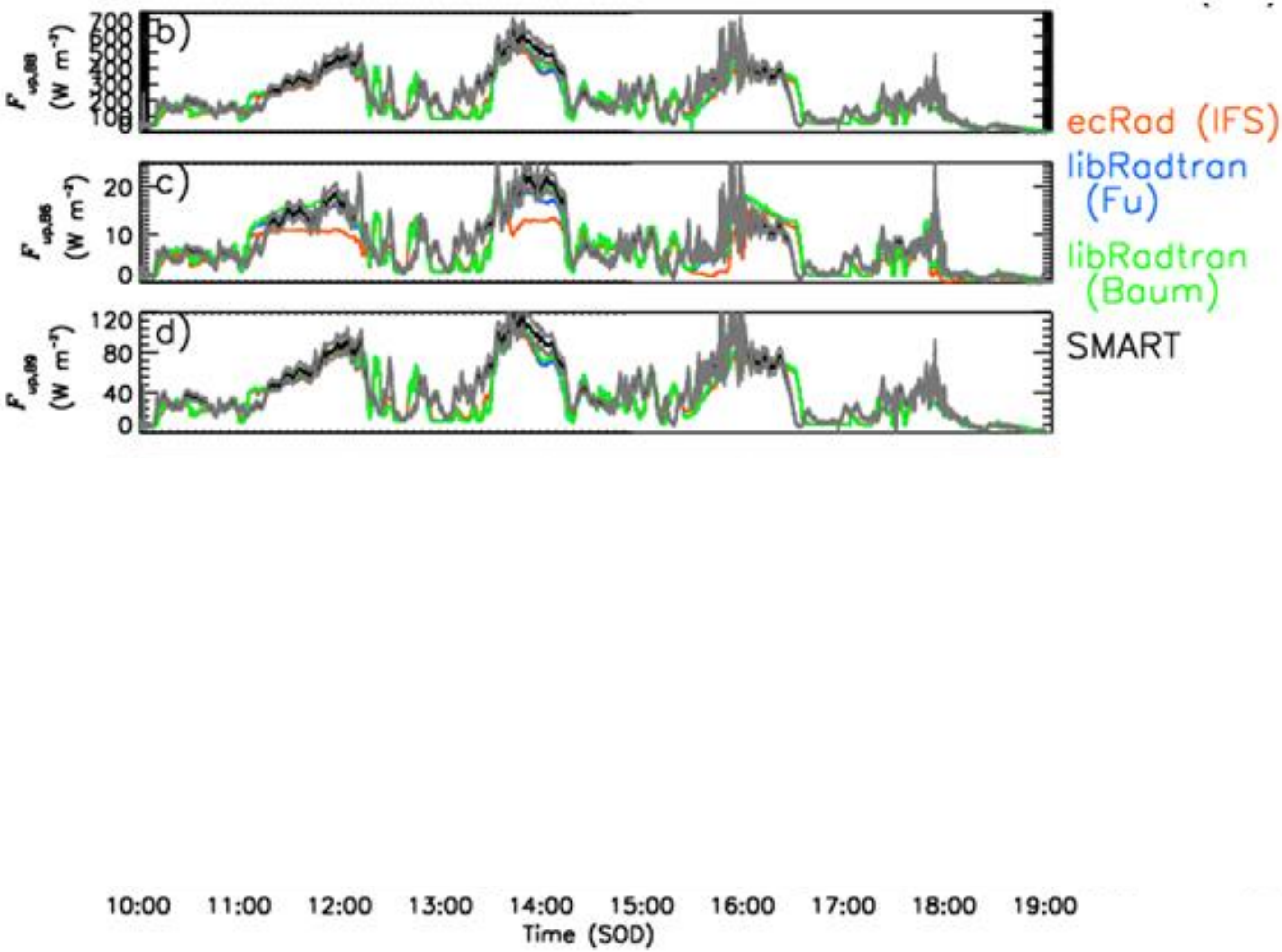

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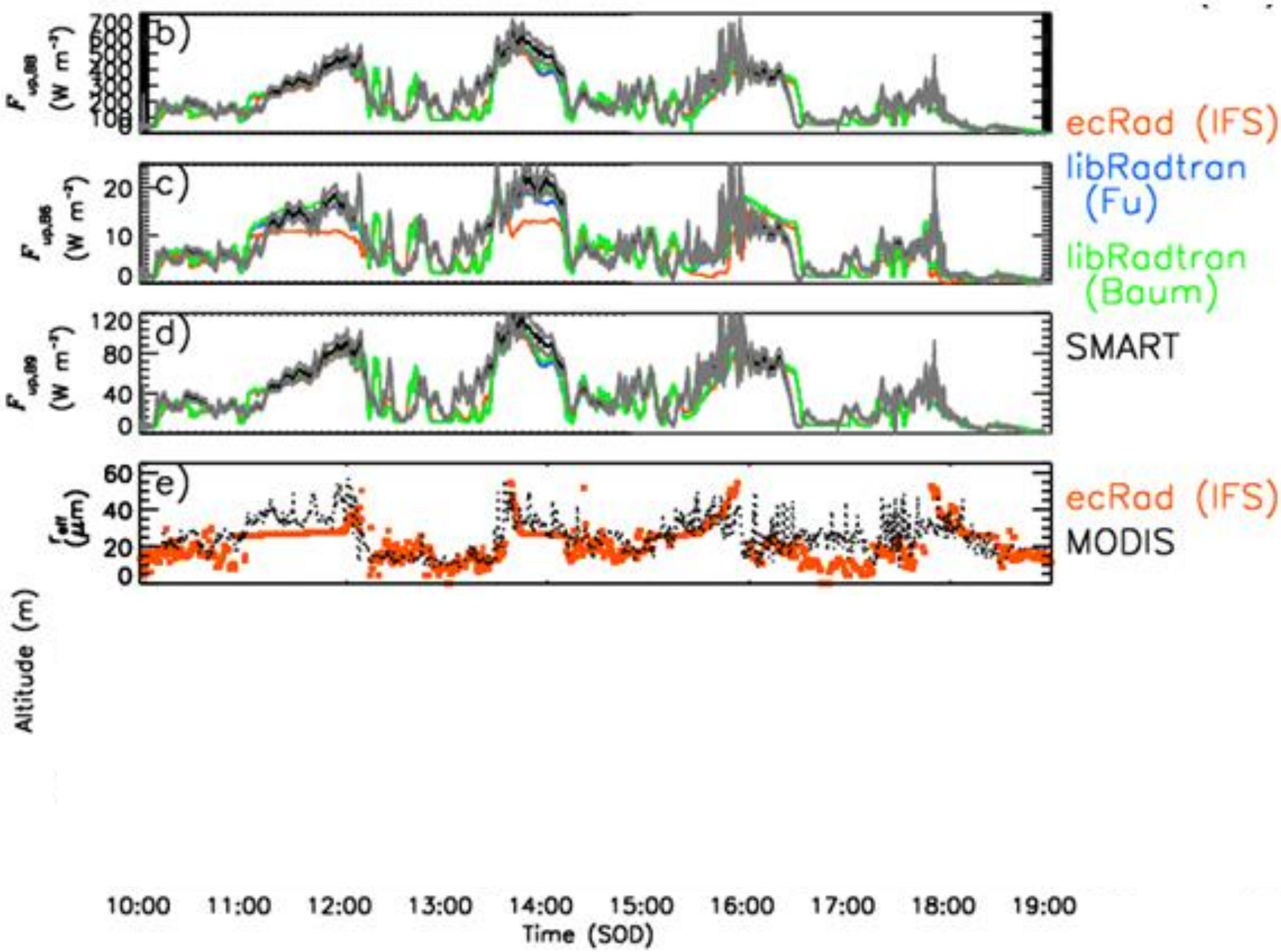

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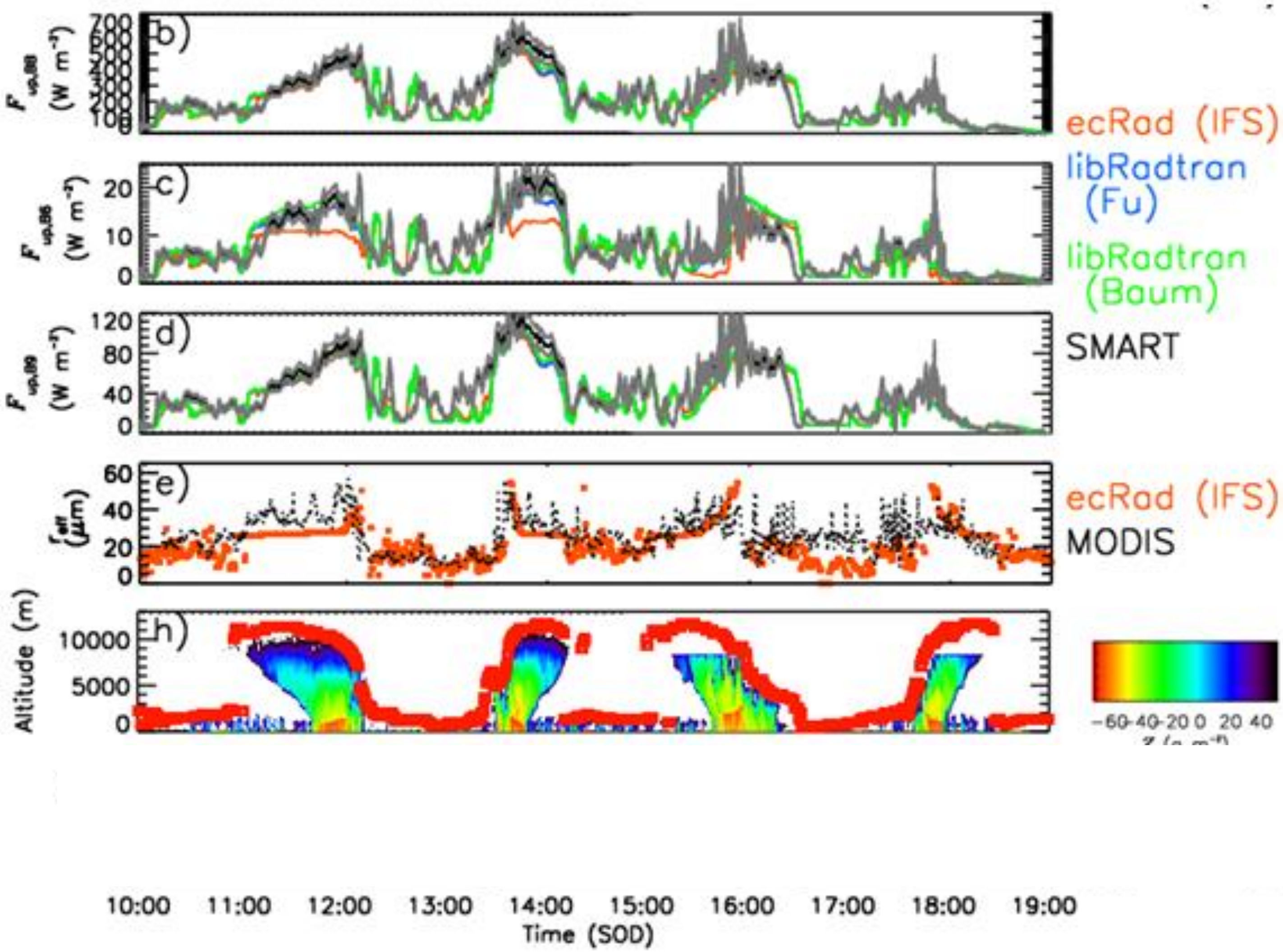

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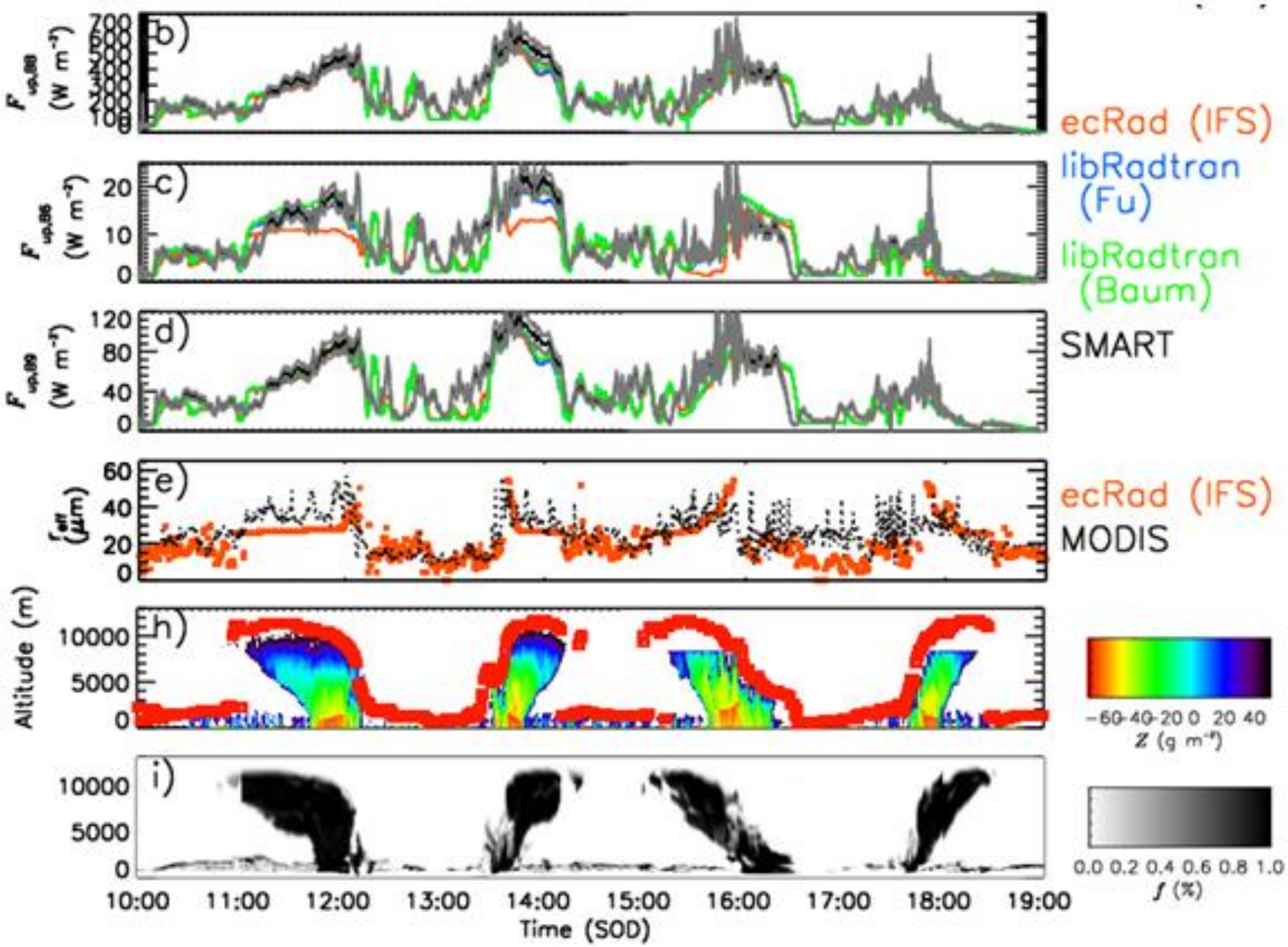

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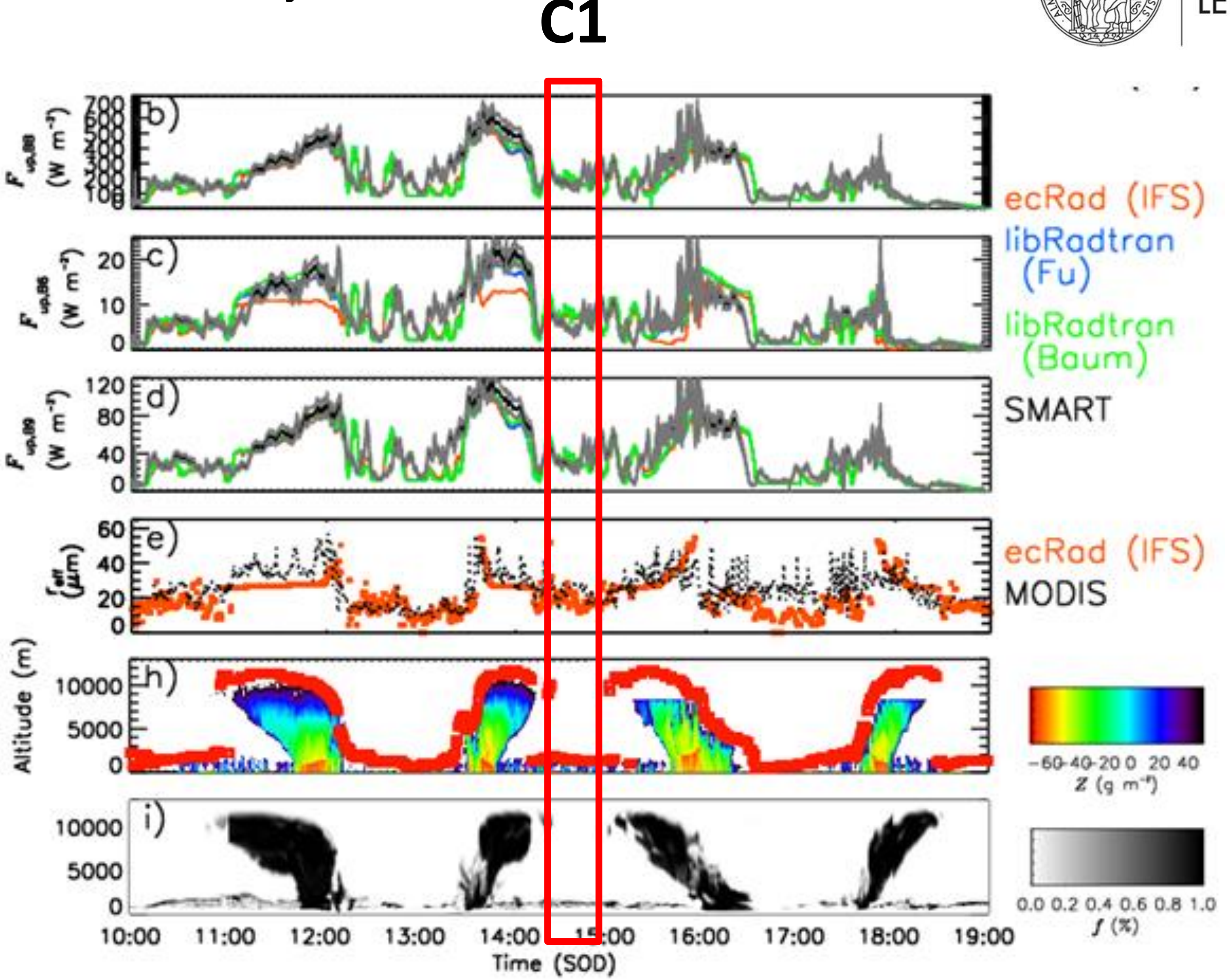

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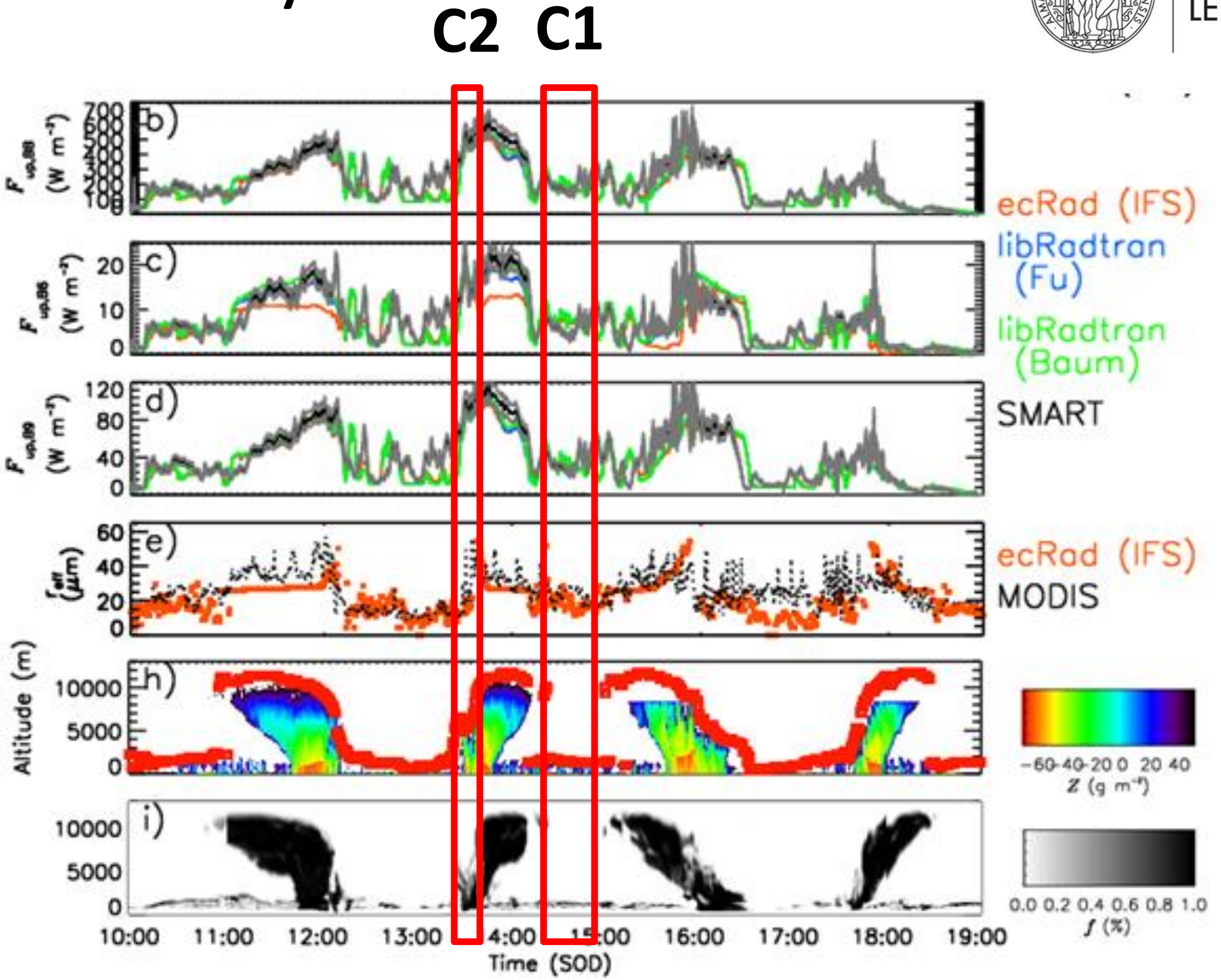

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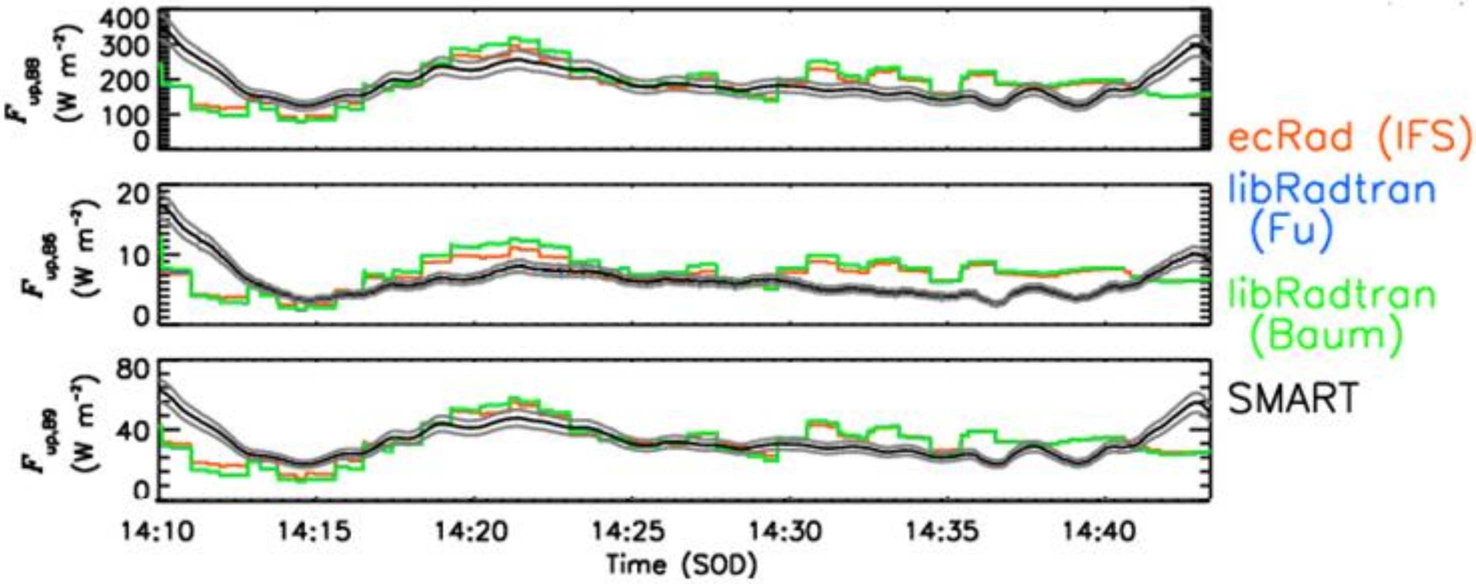
Liquid Water Cloud Case - Timeseries



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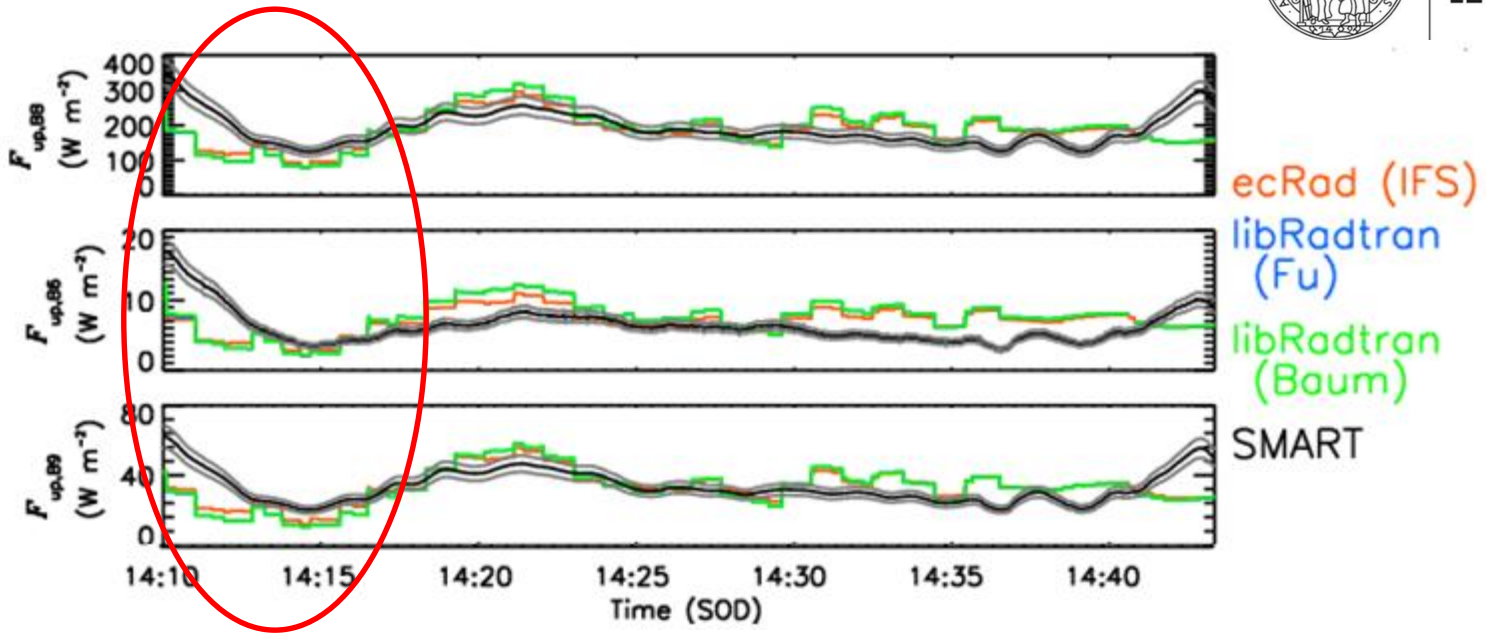

3D Effects

vs

Independent Column Approximation

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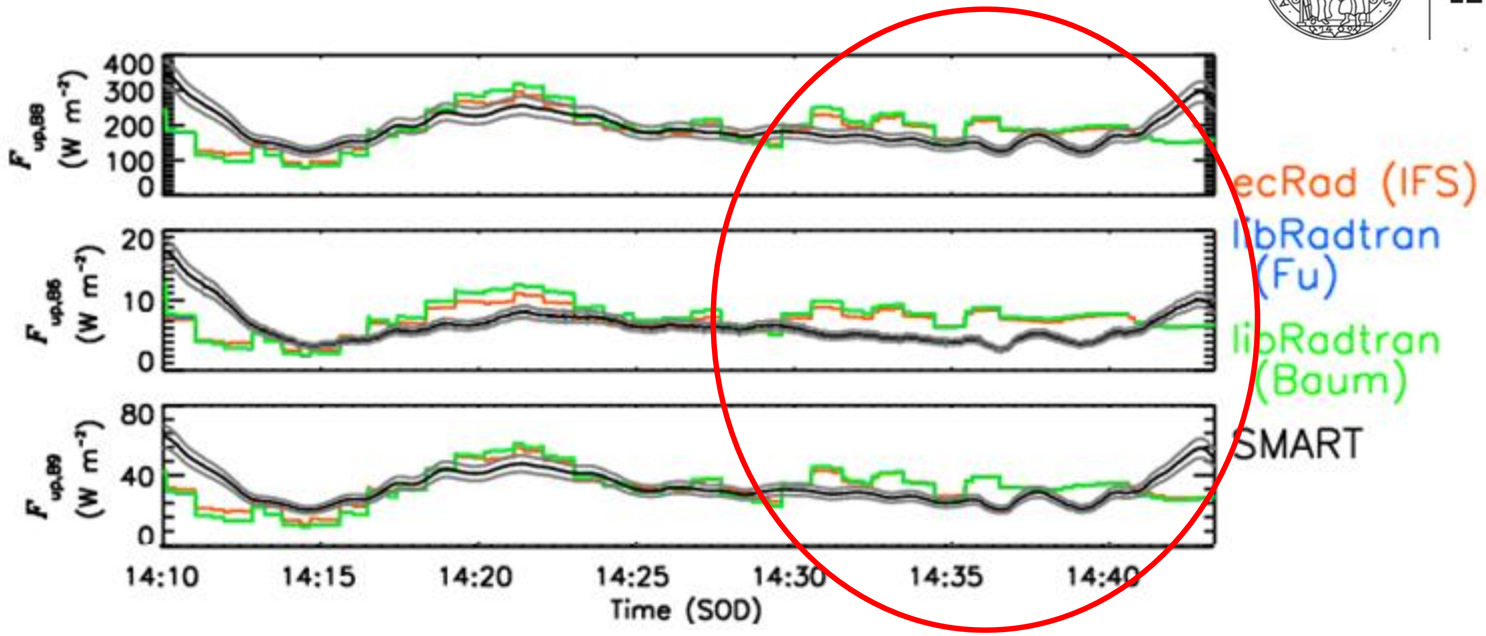
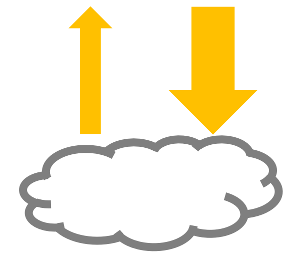
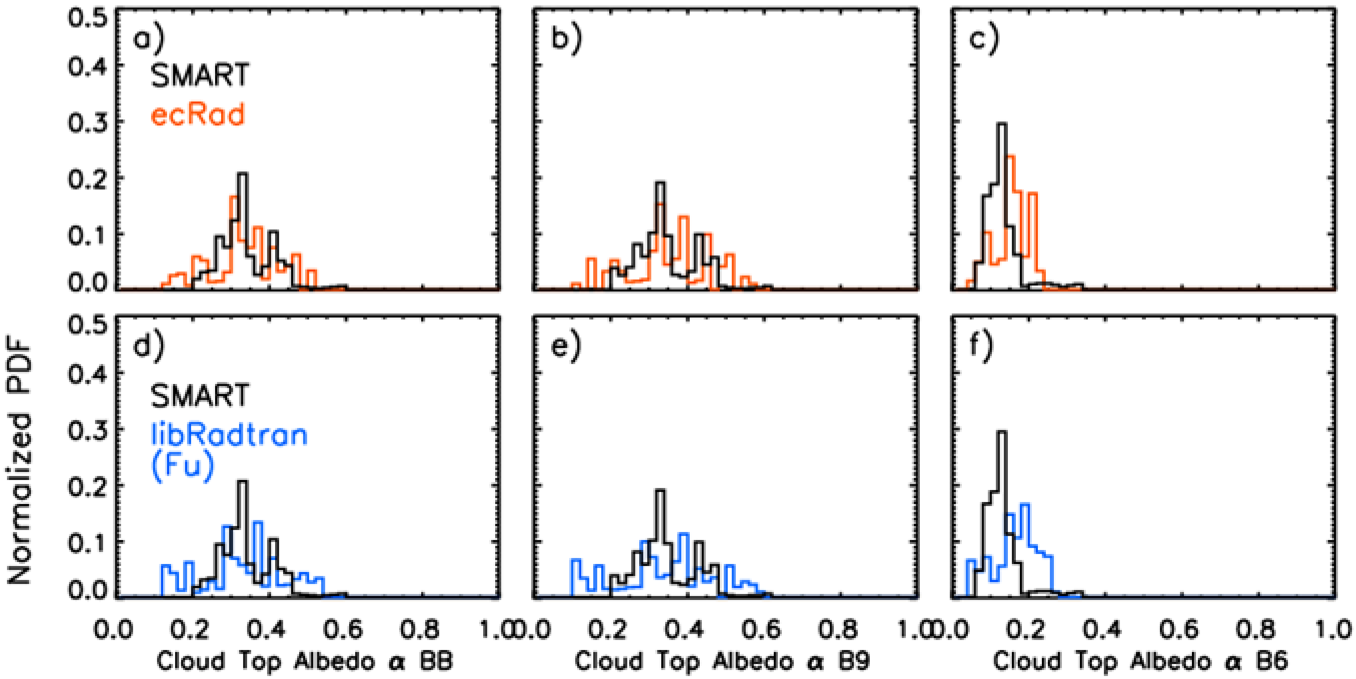


Cloud Representation
in IFS Analysis Data

Liquid Water Cloud Case – Cloud Top Albedo

$$\alpha_\lambda(z_{\mathrm{top}}) = \frac{F_\lambda^{\uparrow}(z_{\mathrm{top}})}{F_\lambda^{\downarrow}(z_{\mathrm{top}})}$$

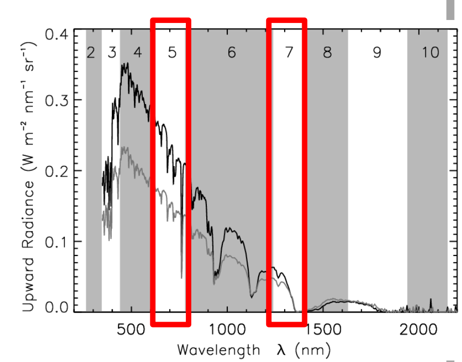




250 - 2500 nm

625 - 778 nm
(#5, scattering)

1242 -1299 nm
(#7, absorption)



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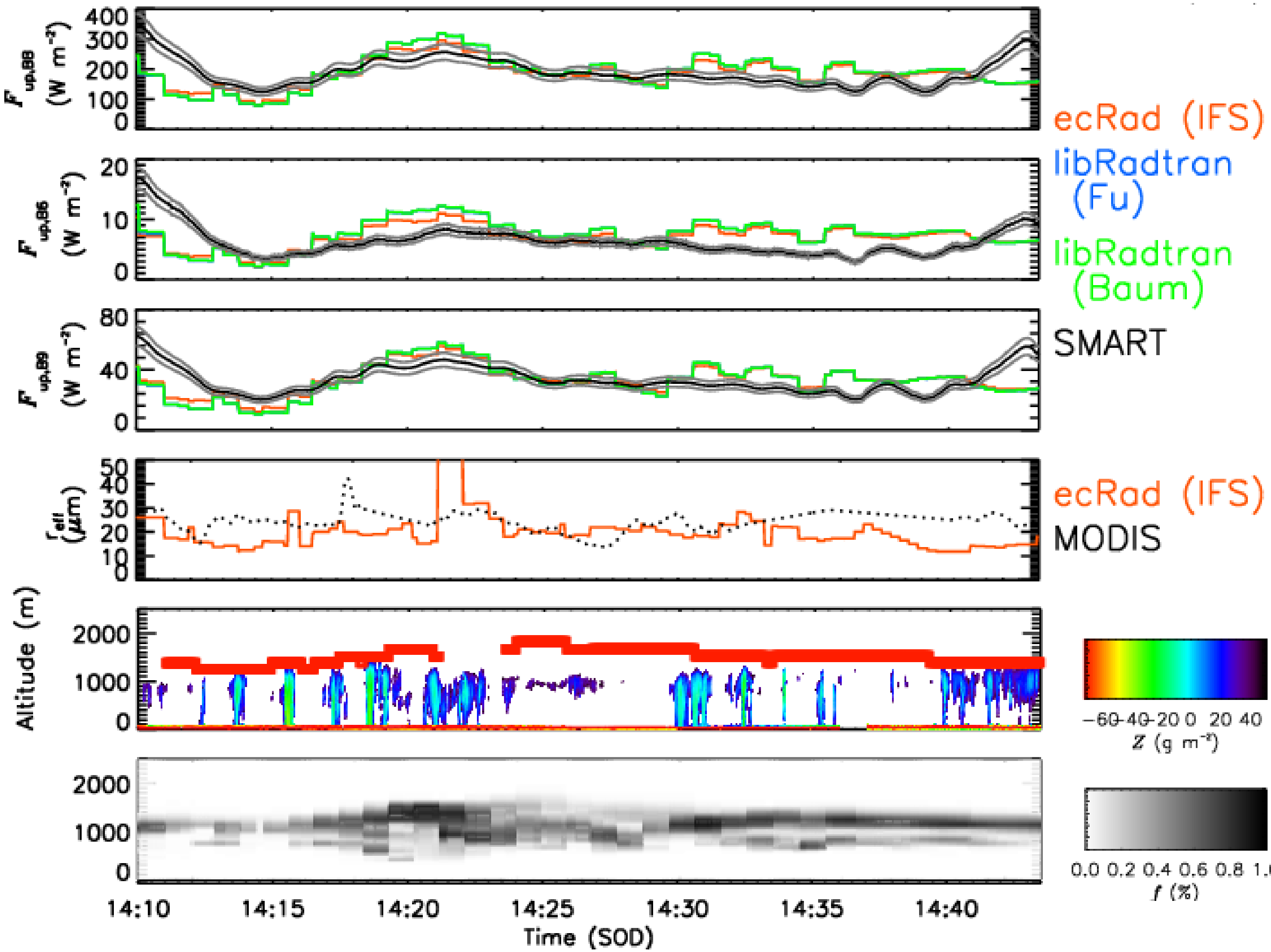
Liquid Water Cloud Case - Timeseries



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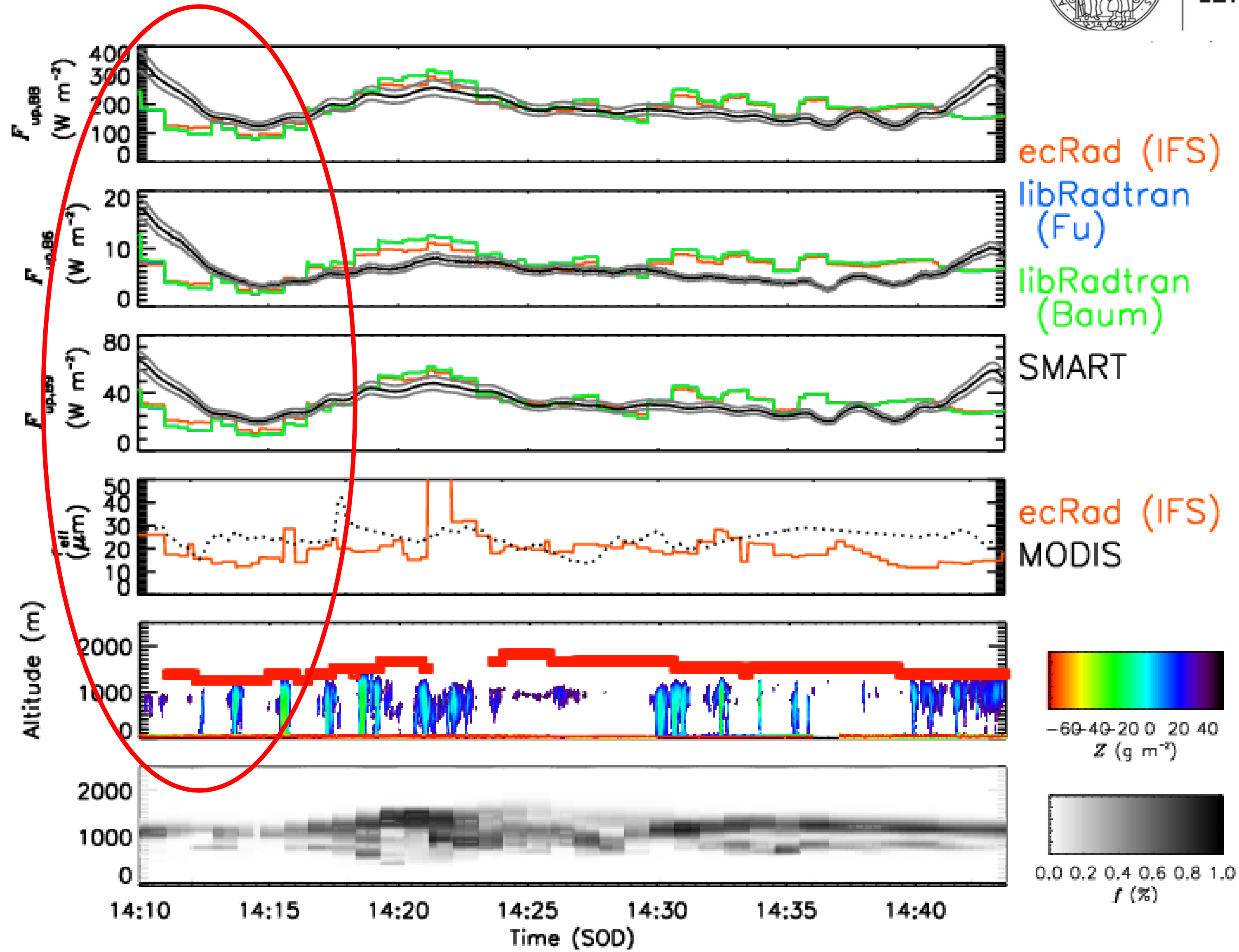

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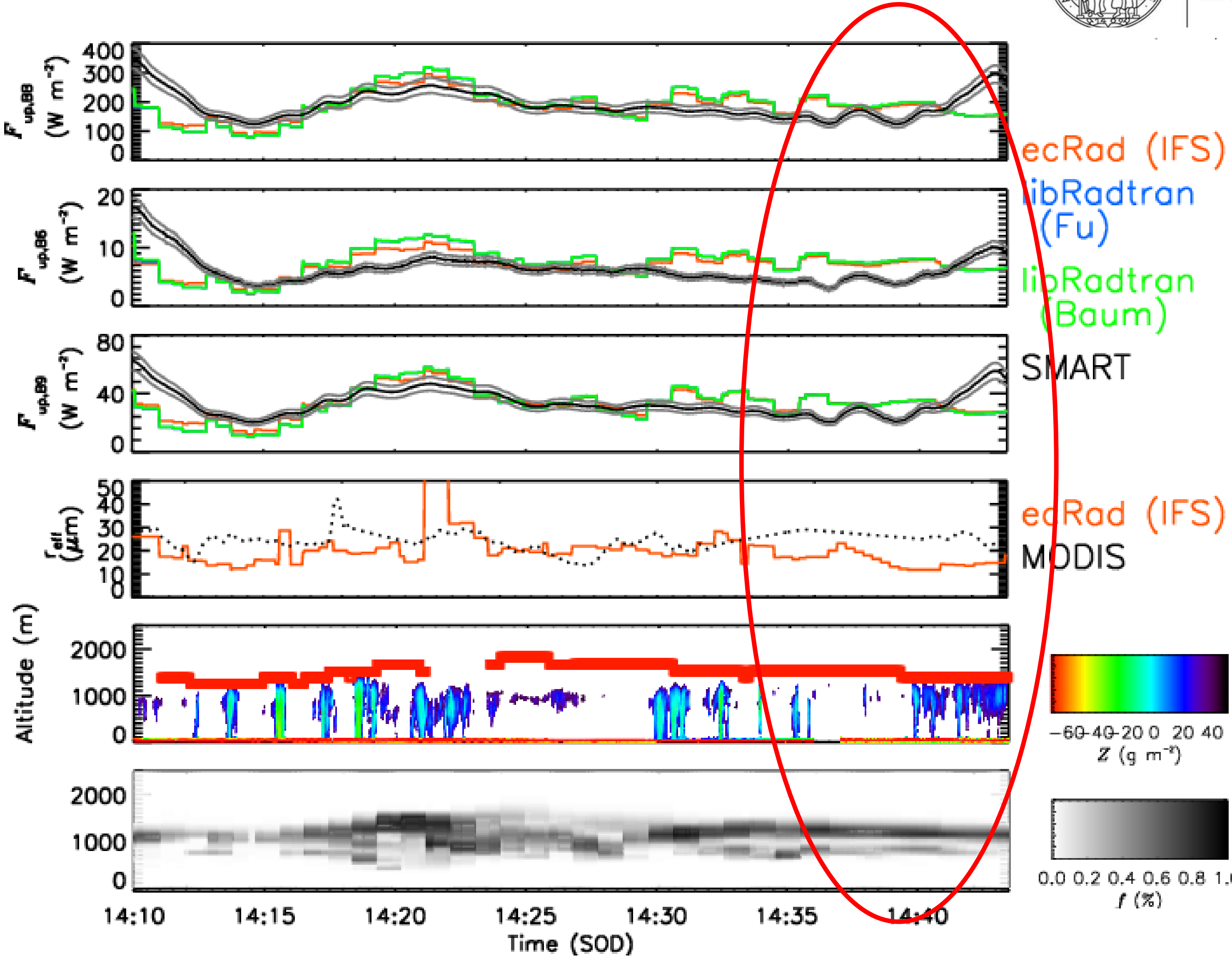

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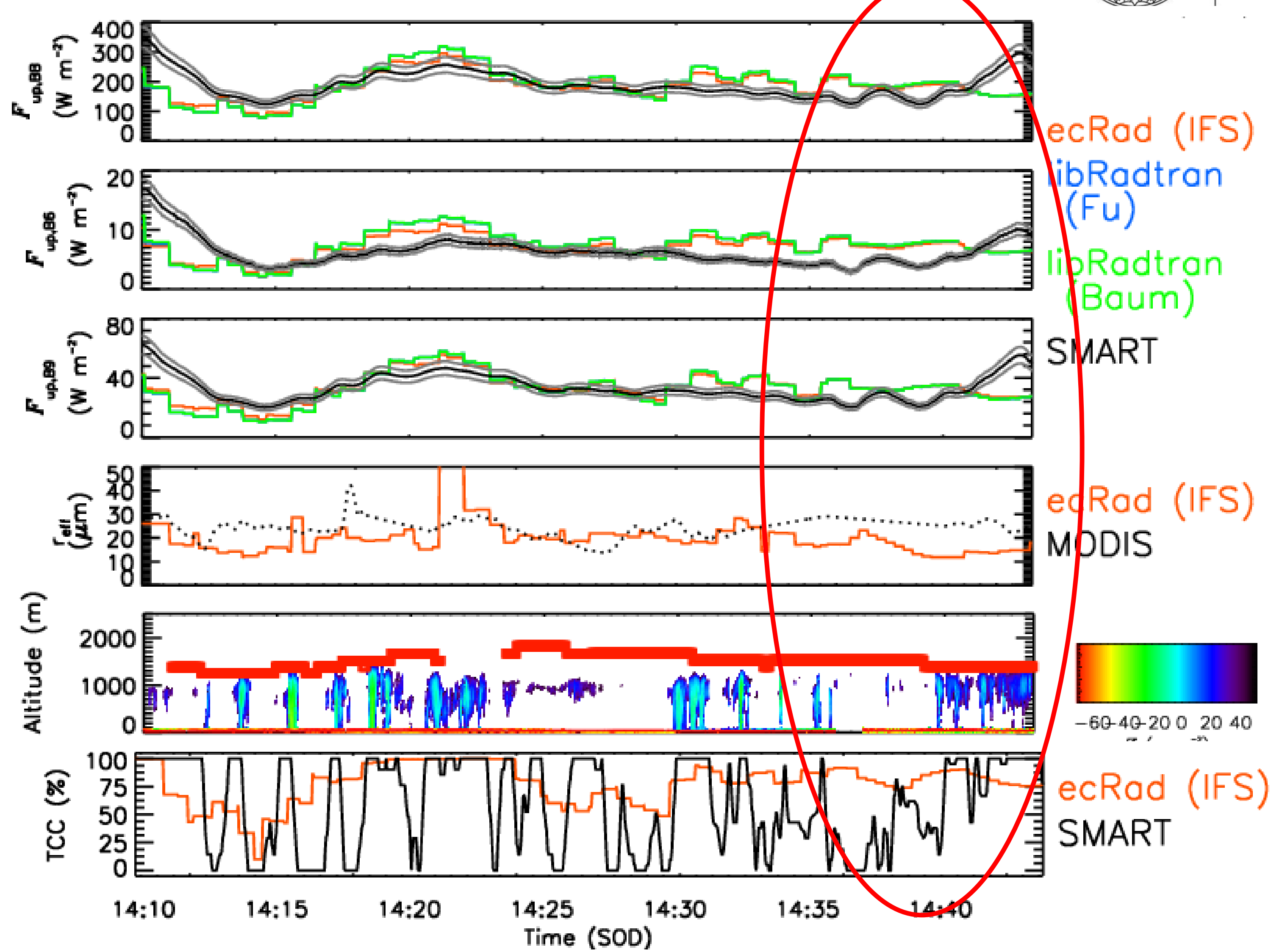

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Ice Cloud Case - Timeseries

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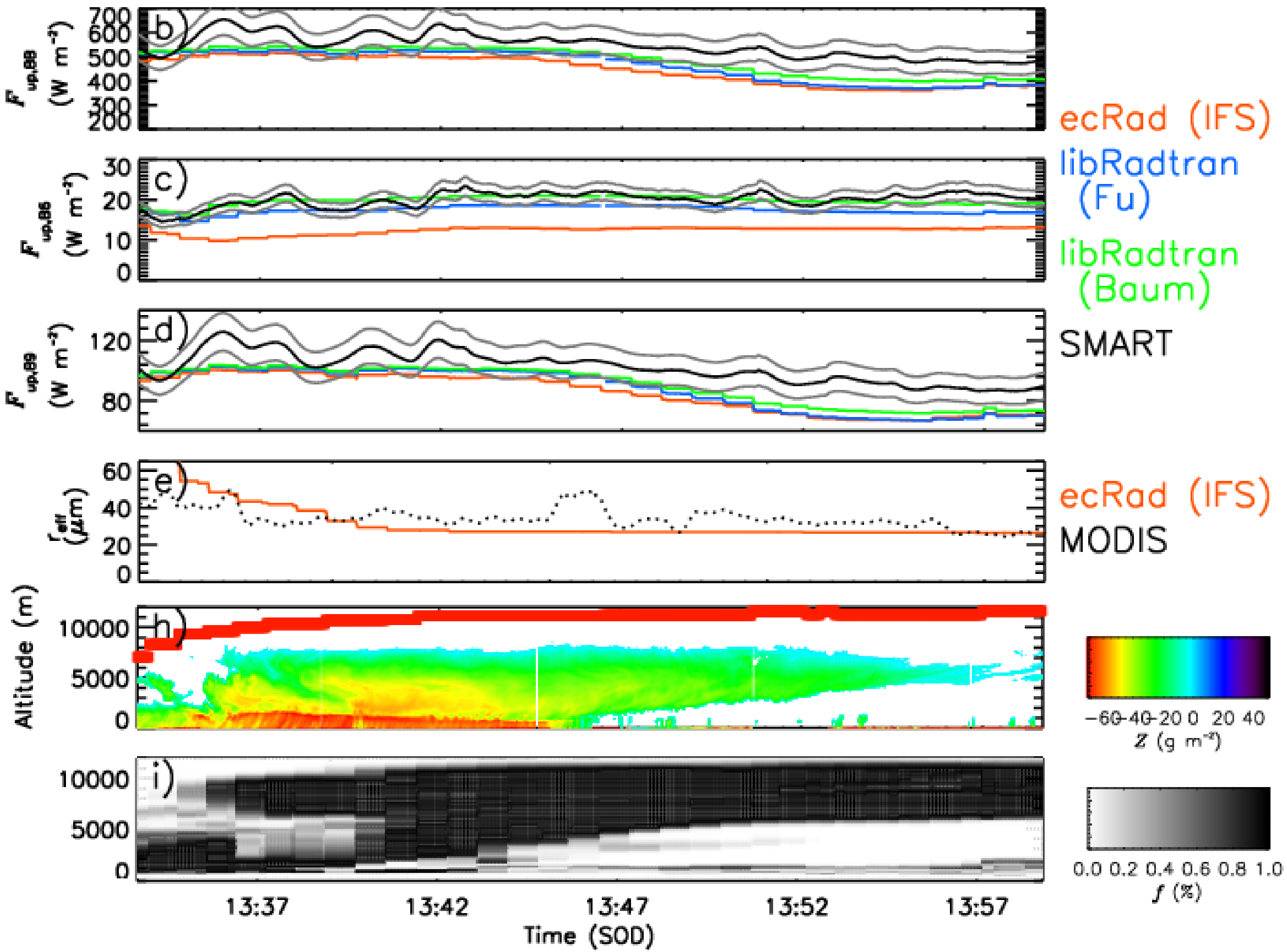
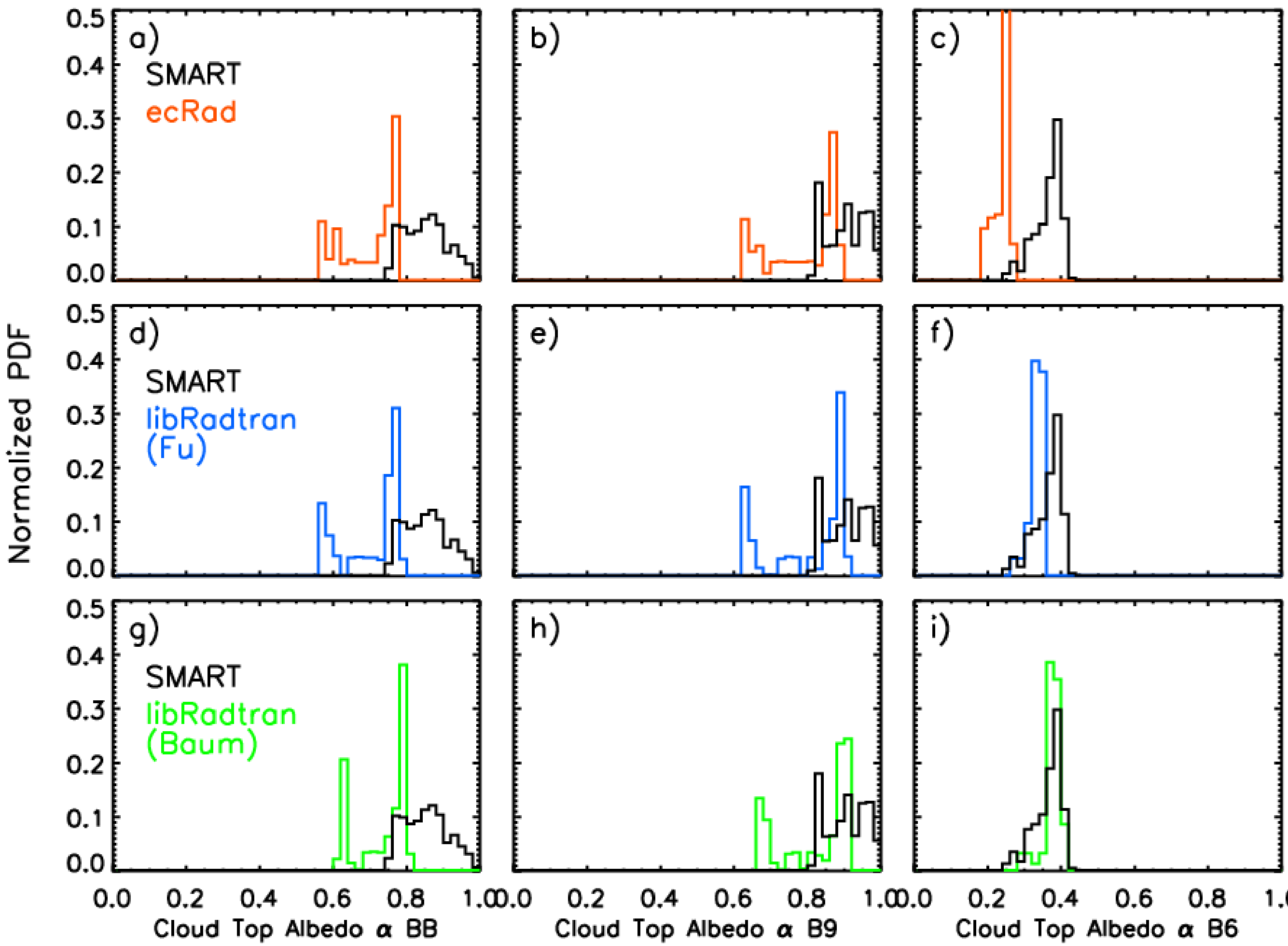


Ice Cloud Case – Cloud Top Albedo



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1242 -1299 nm (#7, absorption)

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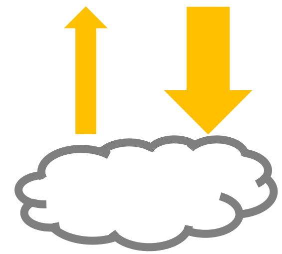

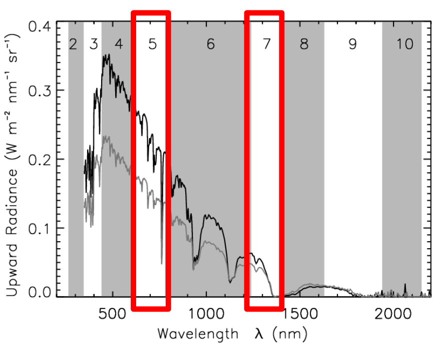

Conclusion

- Co-location of observation and simulation well
- Too large droplet size due to LWC and fractional cloud cover

  (Model error)
- Too low reflection of ice water clouds in absorption bands

  (Radiation scheme error)

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Thank you

for

your attention.

Entire flight

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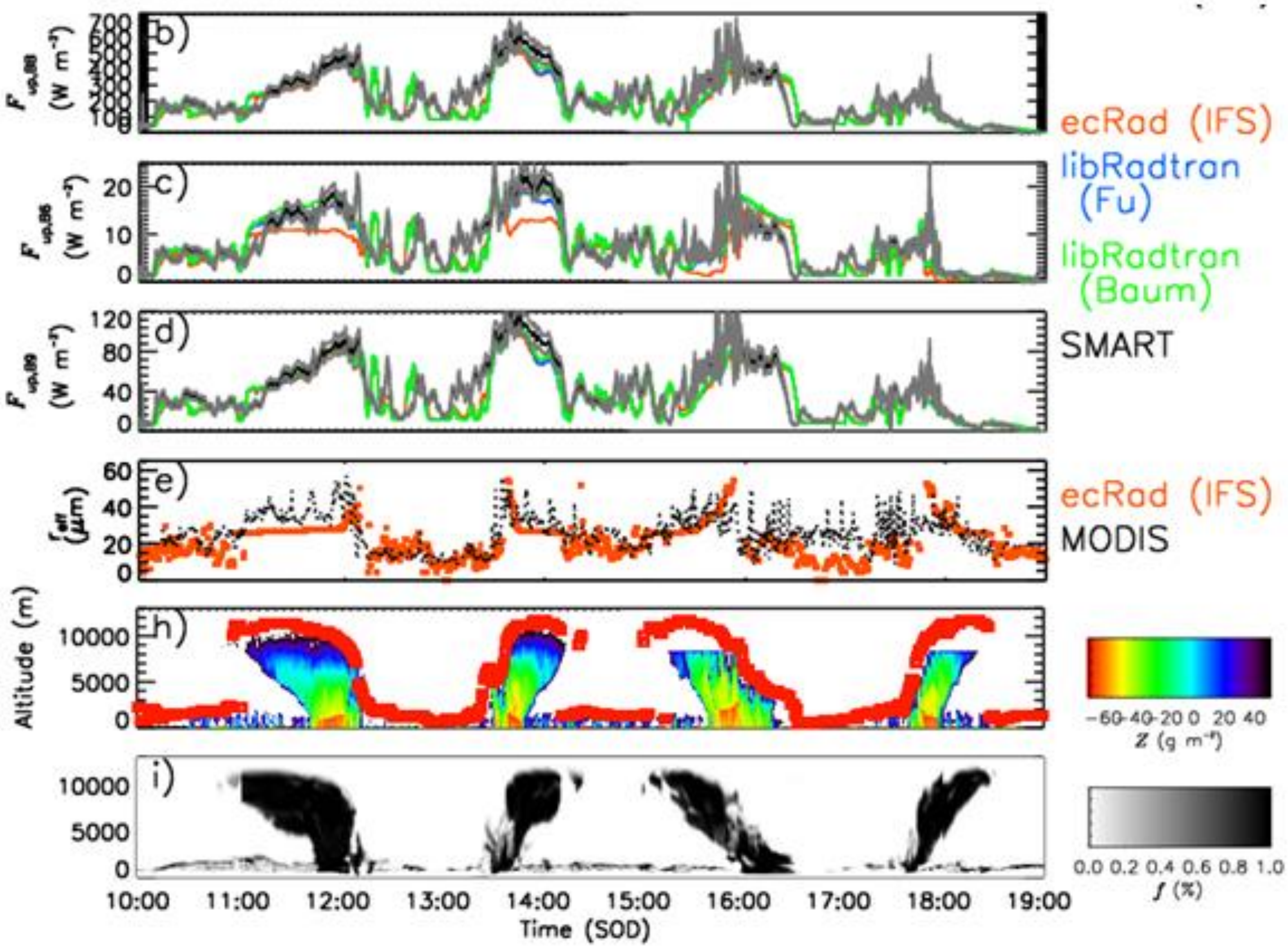
Case Study – time series



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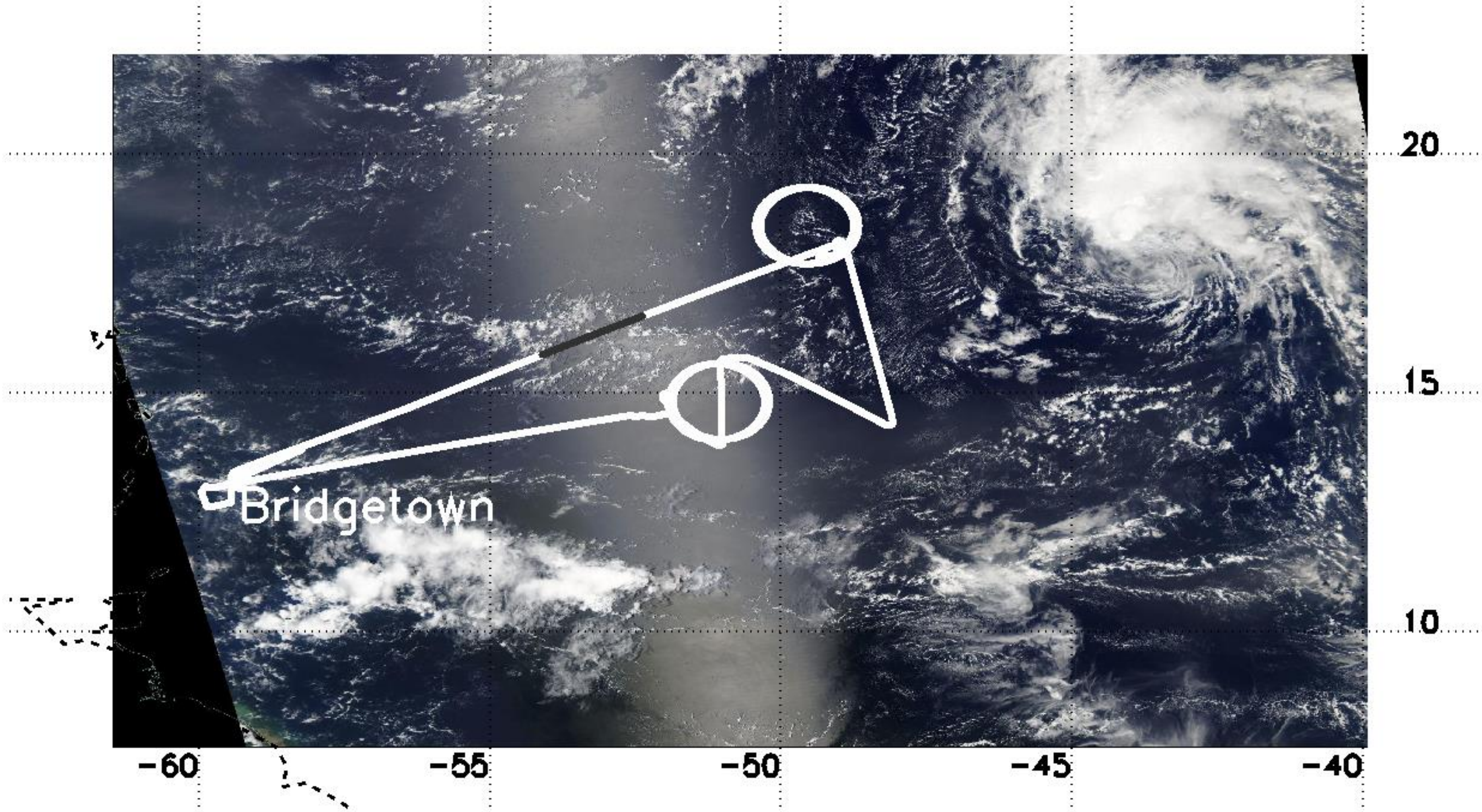
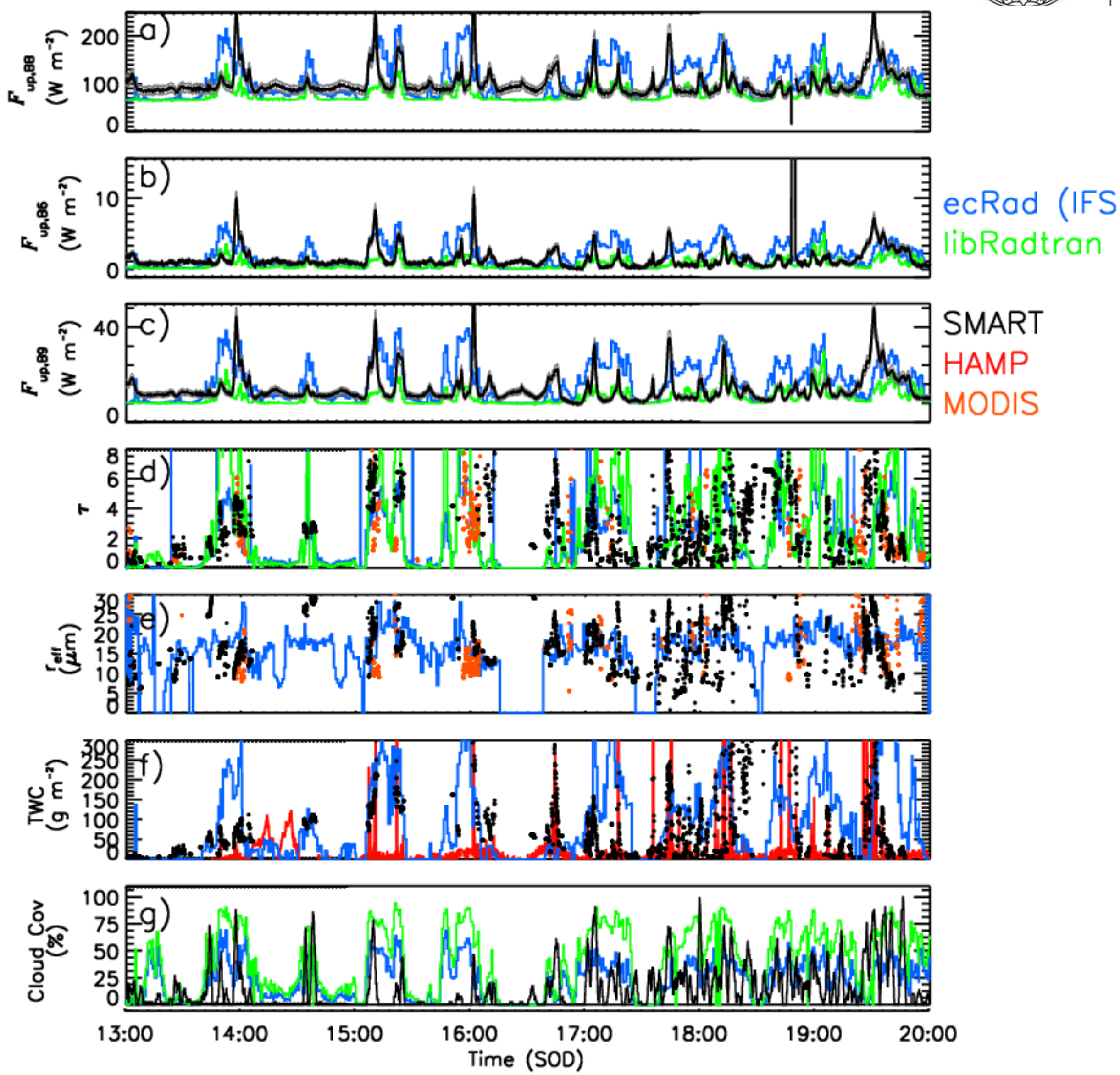
NARVAL-II --Trade wind cumulus region



Modis Aque satellite image from 19 August 2016 with entire flight track of HALO (white) and selected cloud cases (gray) .

NARVAL-II Trade wind cumulus region



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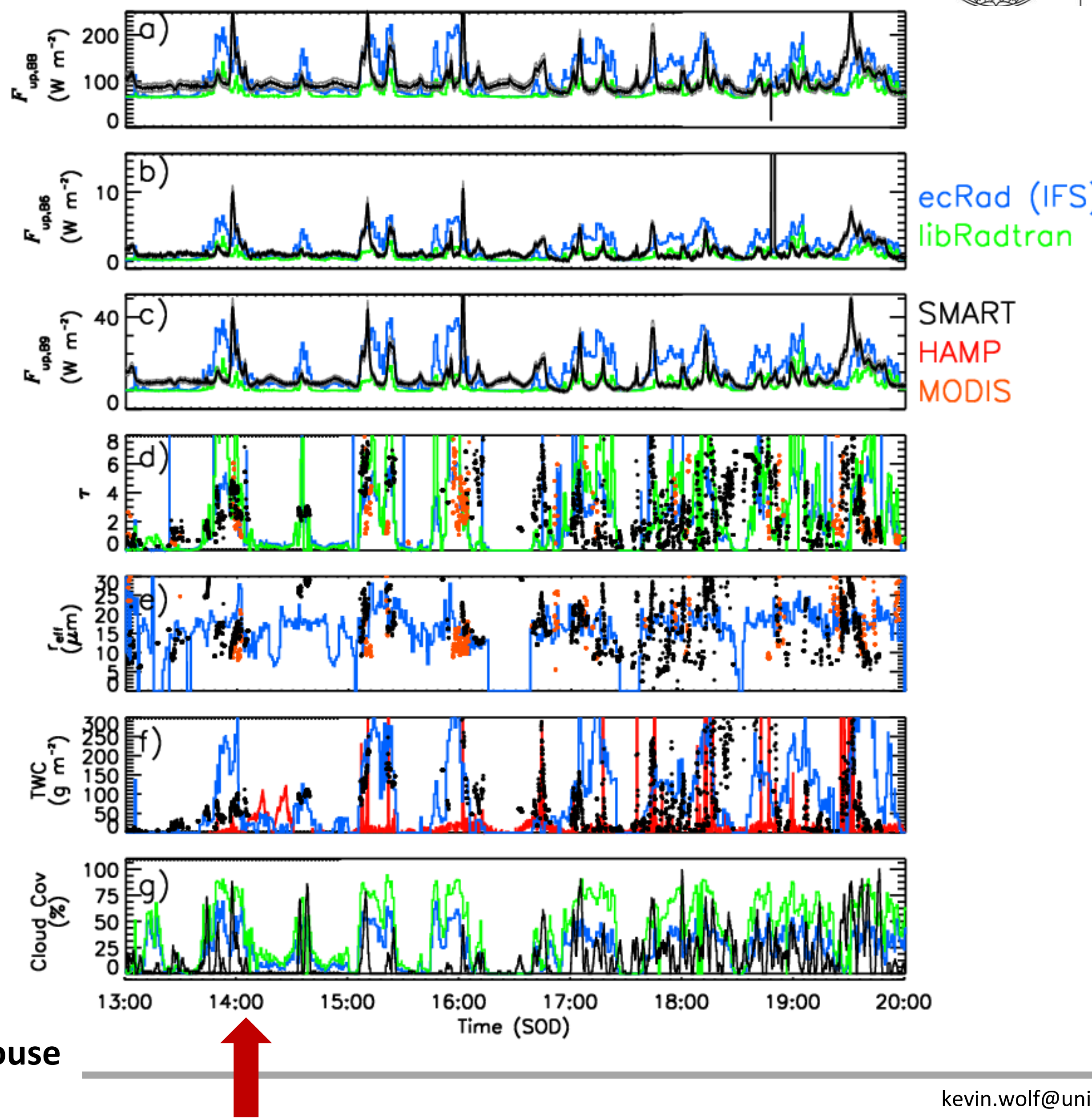

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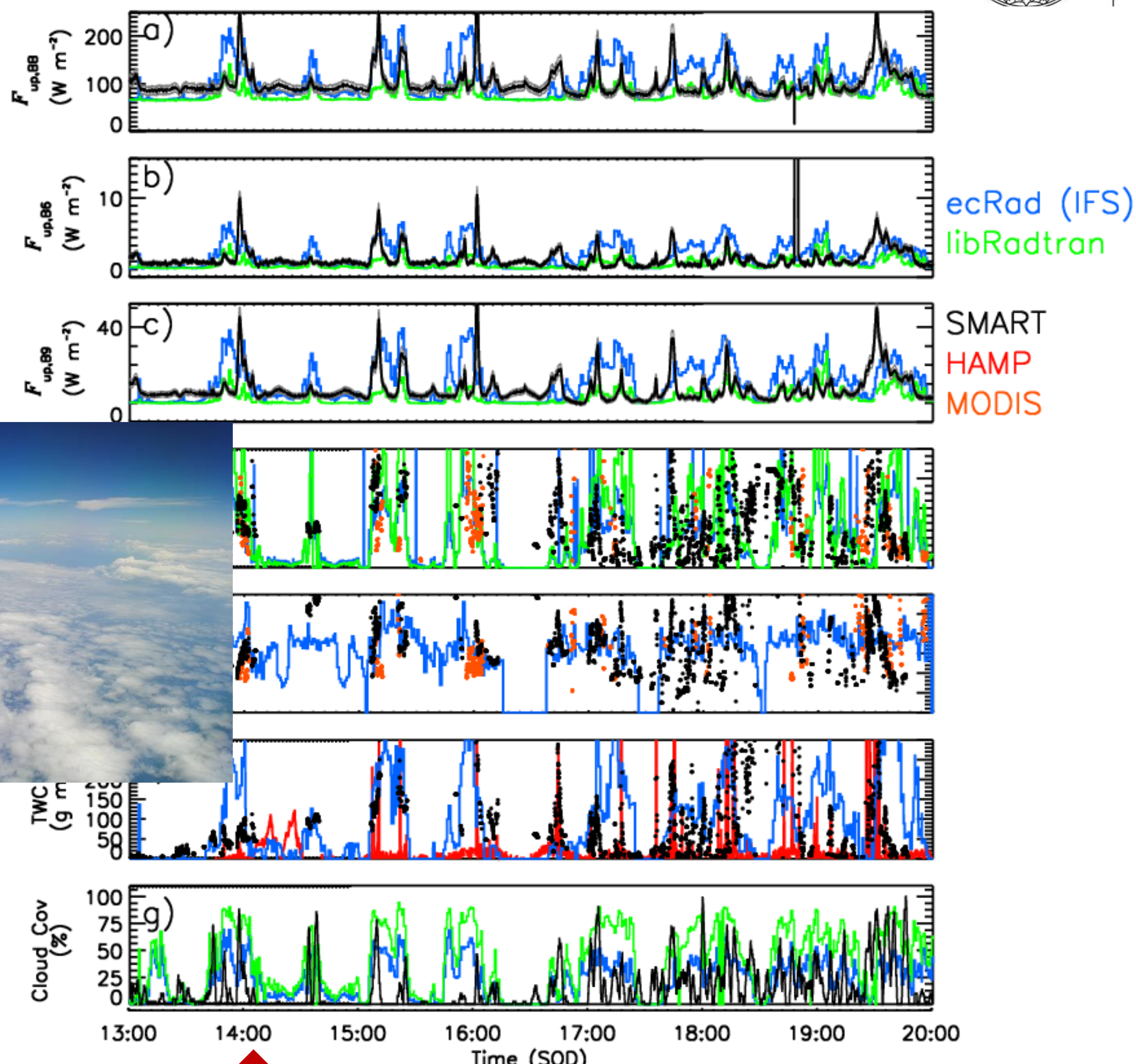

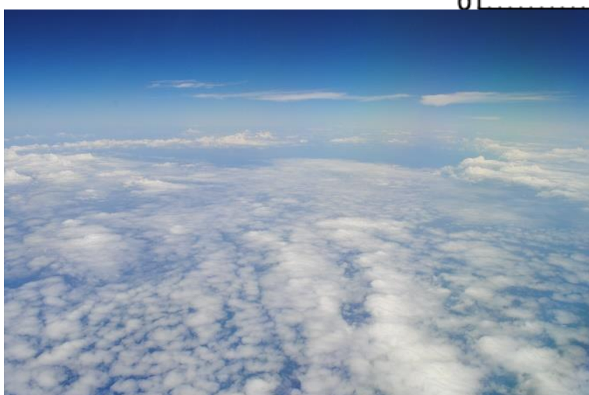

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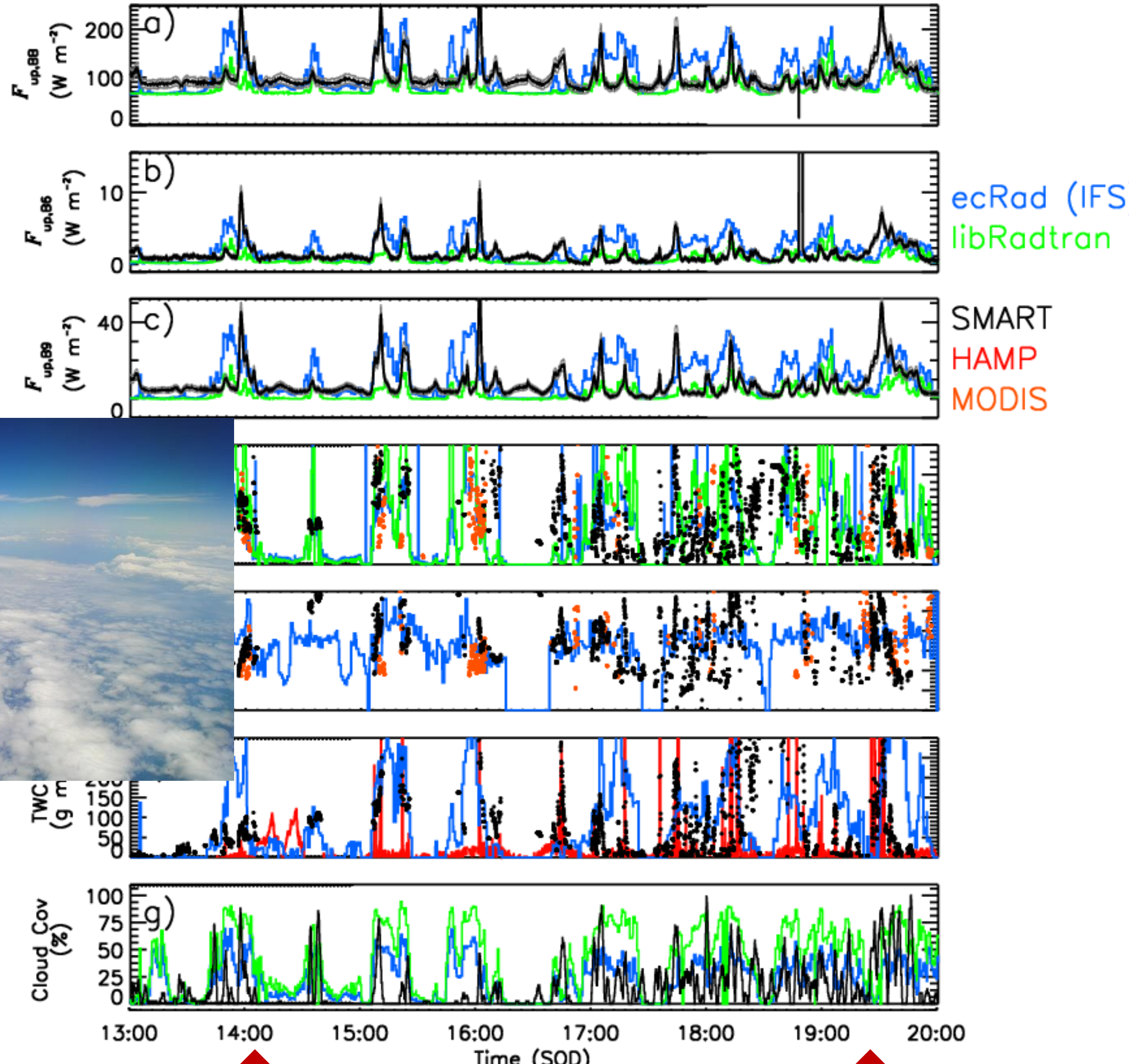

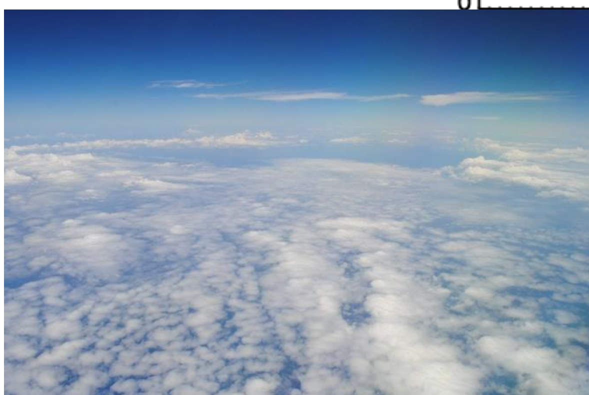

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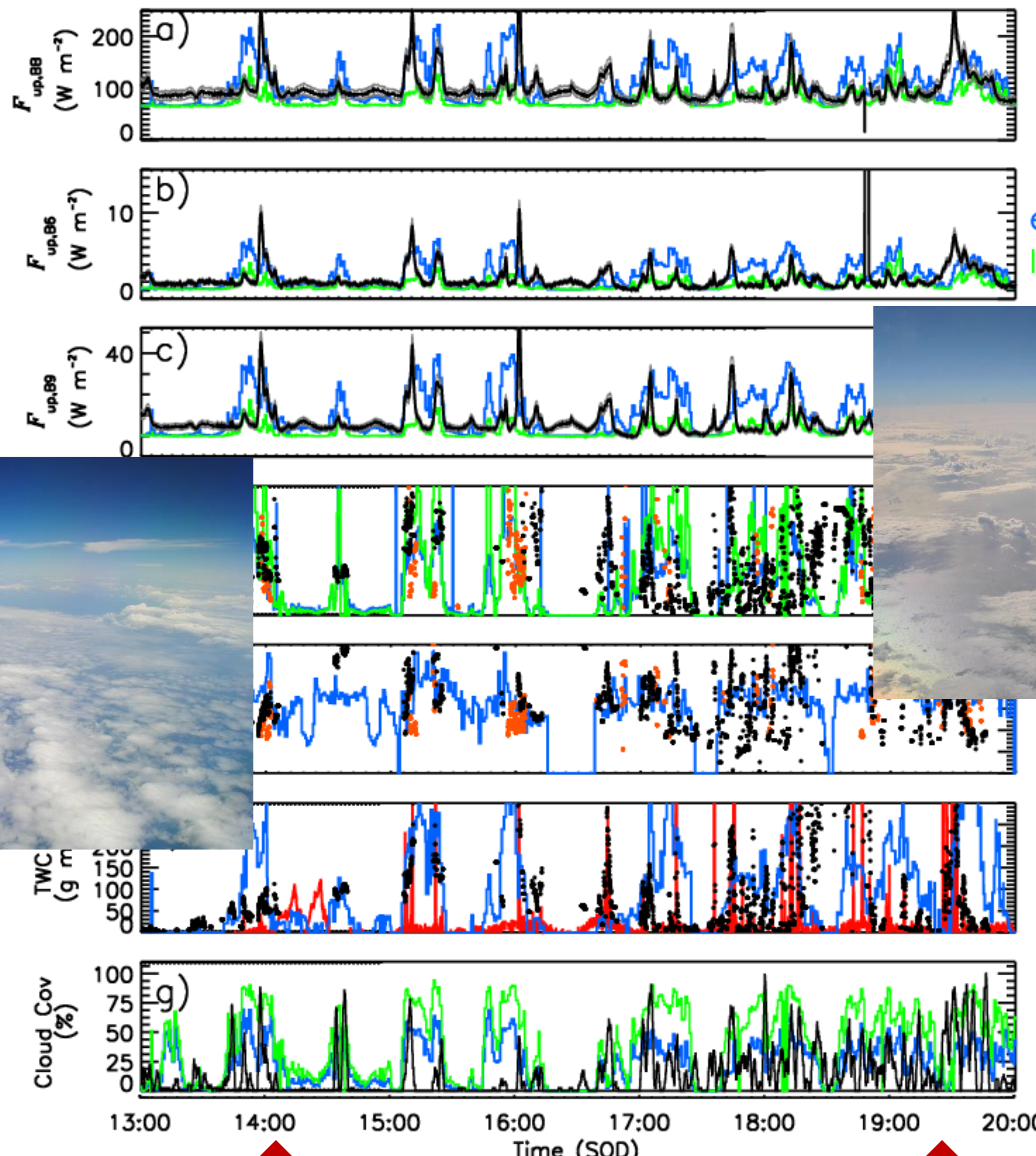

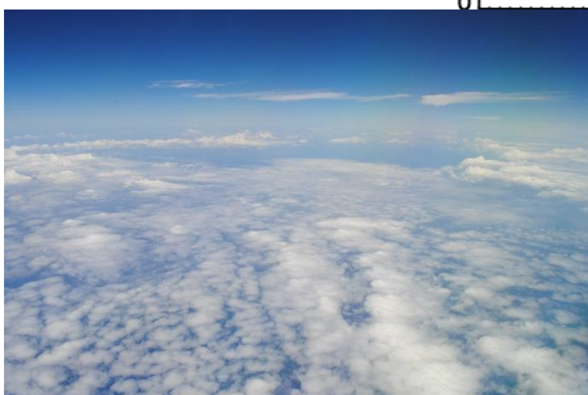

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NARVAL-II Trade wind cumulus region

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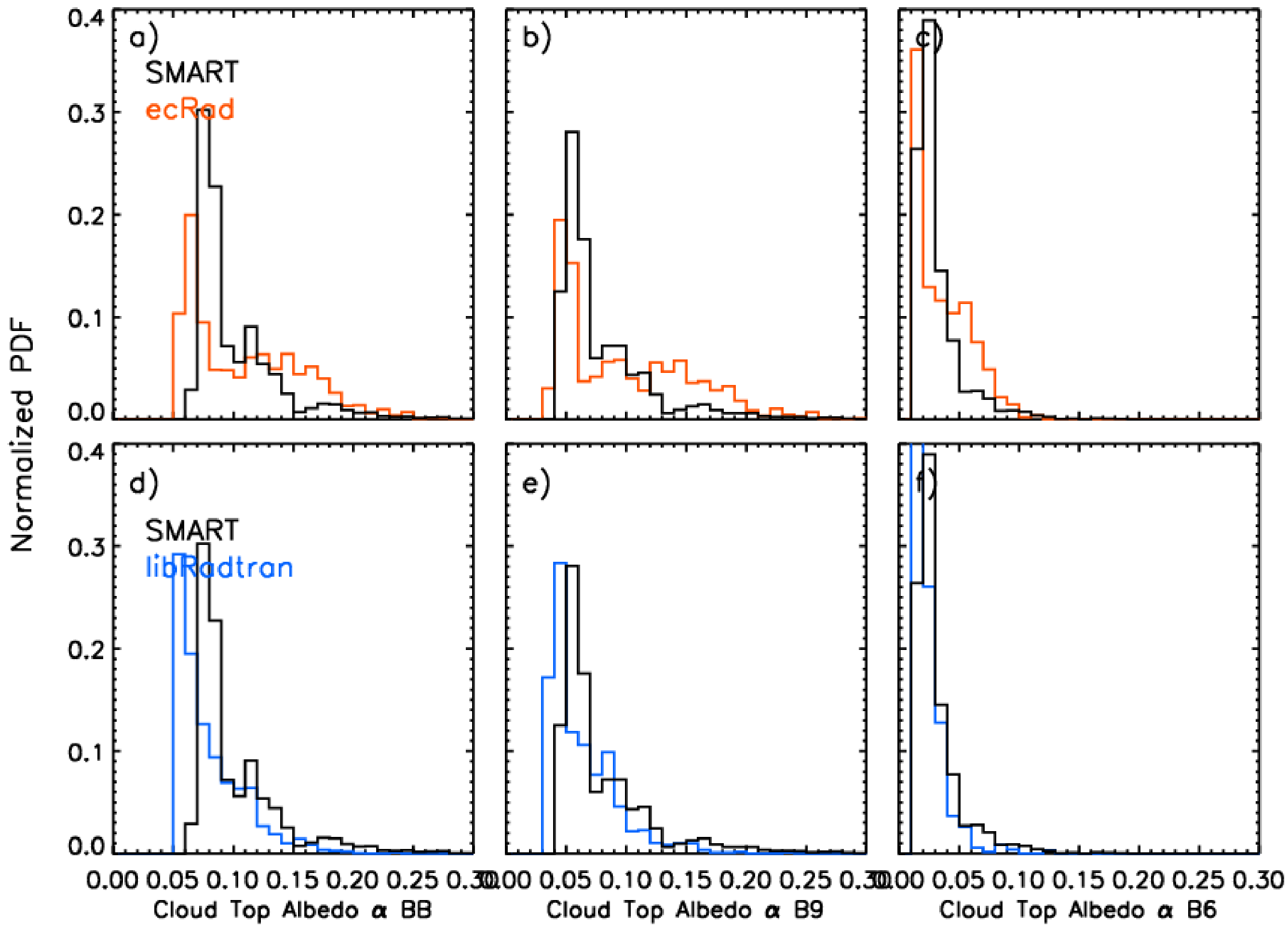

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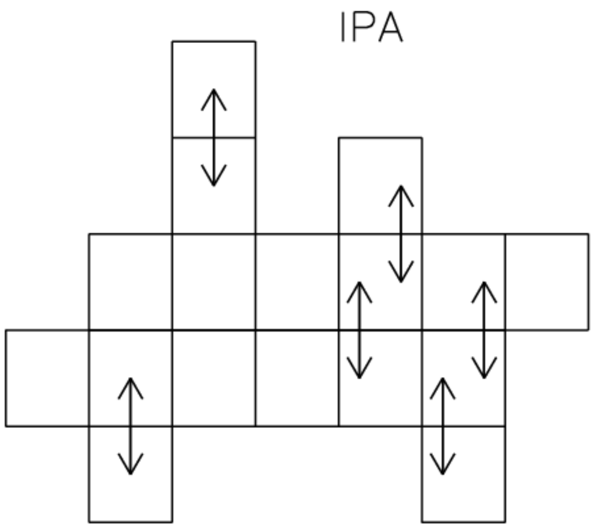
Outlook

- Estimate uncertainty due to simulation method

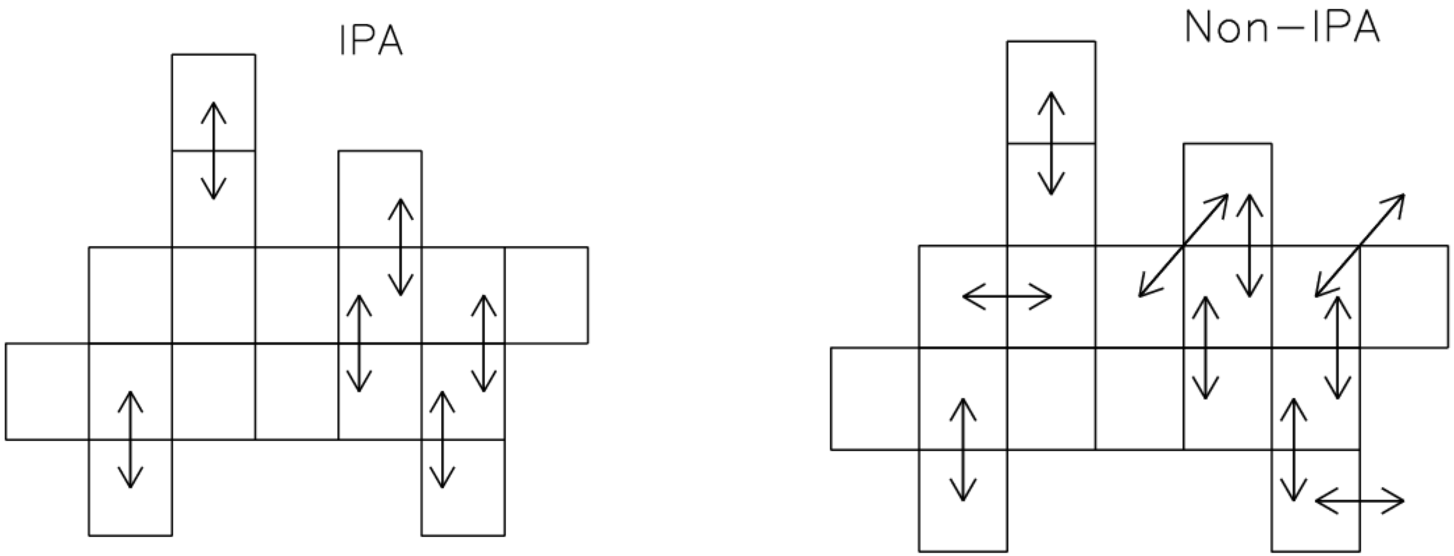
  Independent Pixel Approximation



Outlook

- Estimate uncertainty due to simulation method

  Independent Pixel Approximation



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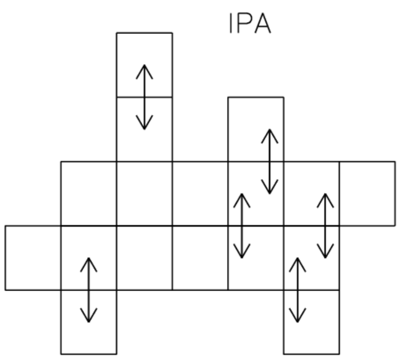
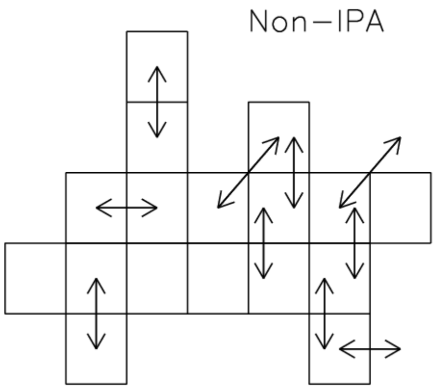
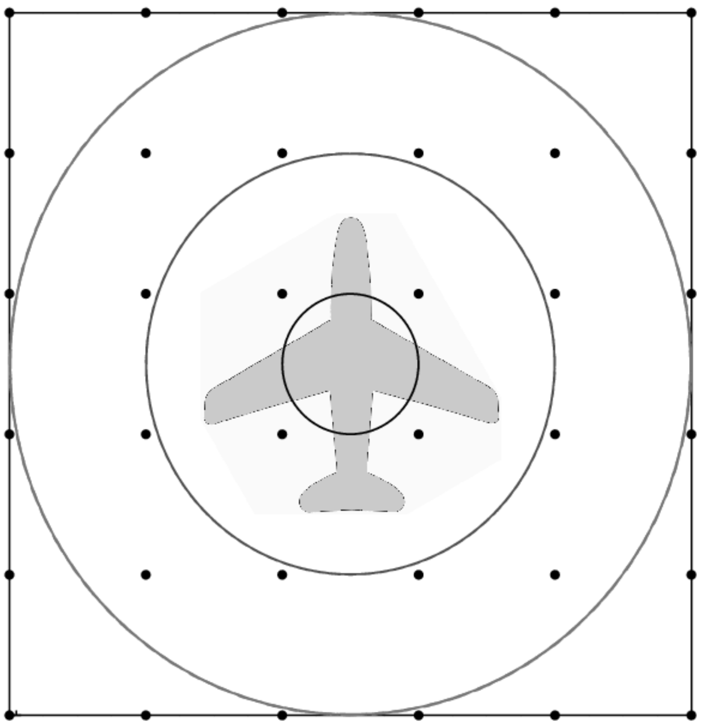
Outlook

- Estimate uncertainty due to simulation method

  Independent Pixel Approximation







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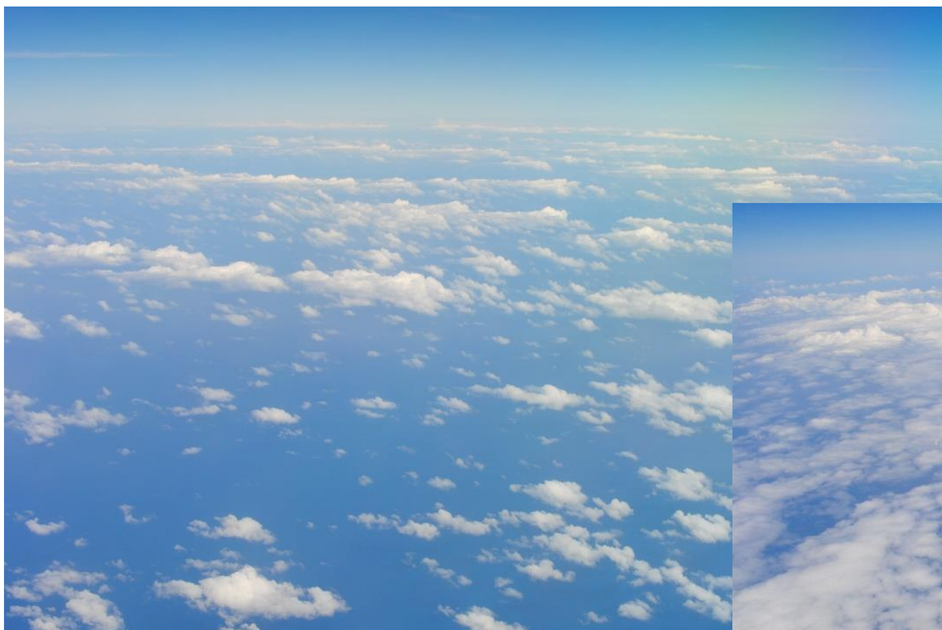
Outlook

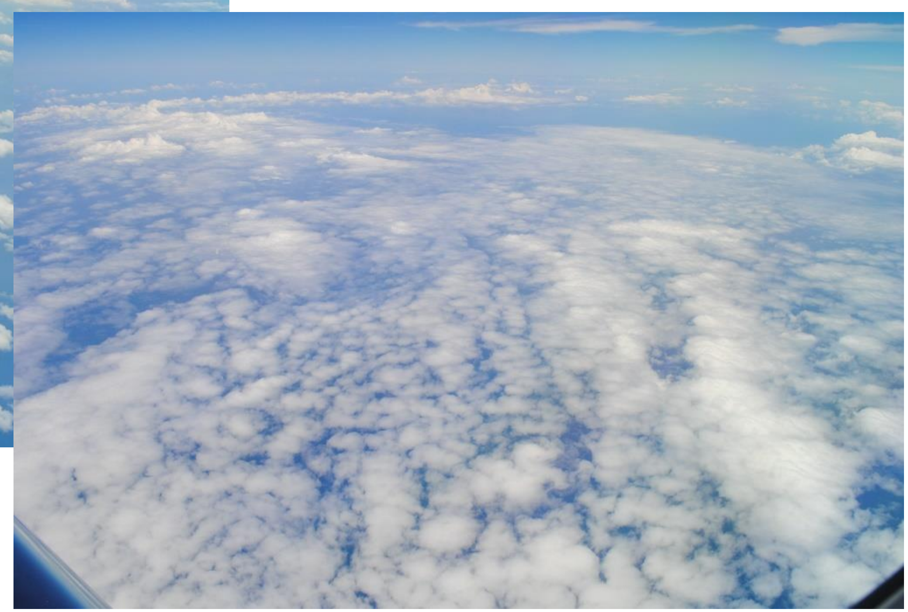
- Estimate uncertainty due to simulation method

  Independent Pixel Approximation

- Case Study for Tropics

  Shallow trade-wind cumulus





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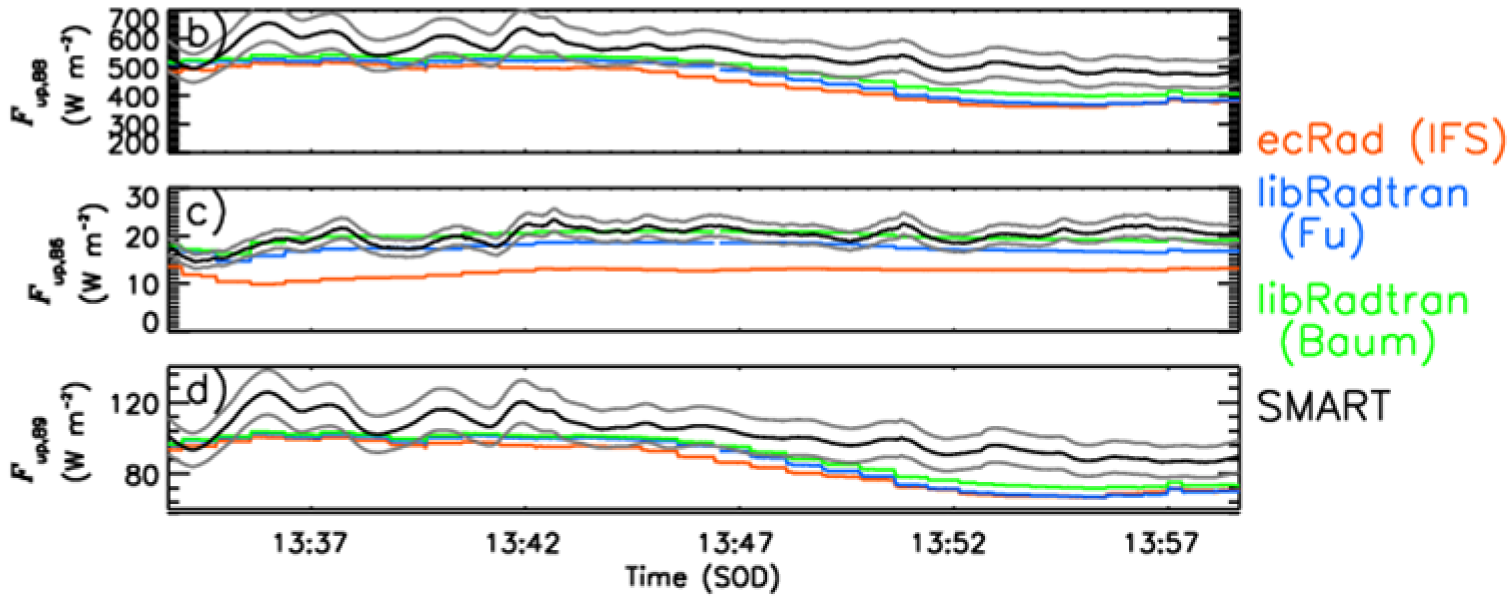
Ice Cloud Case - Timeseries



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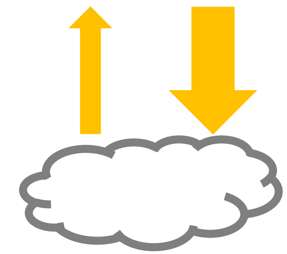
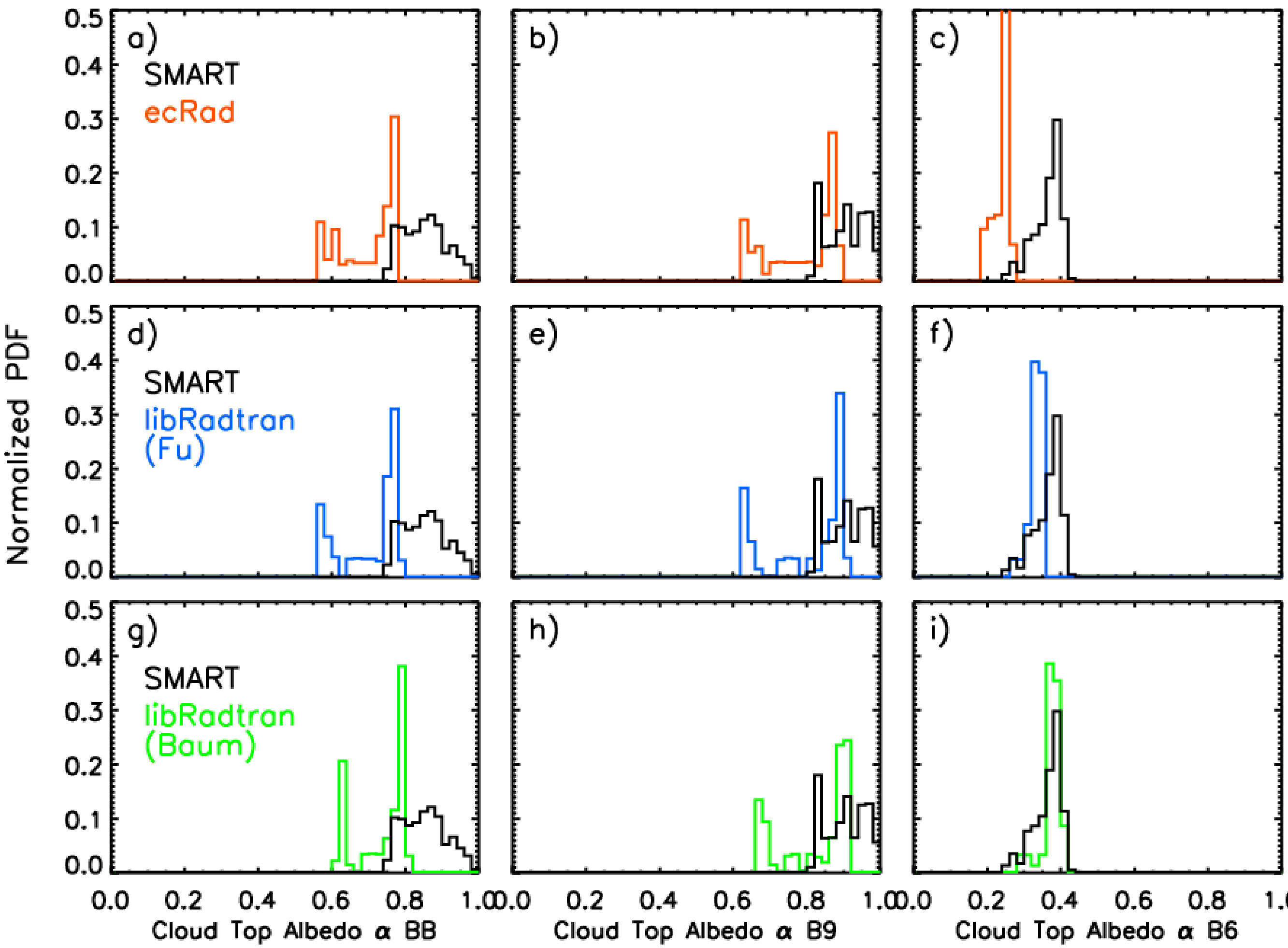
Ice Cloud Case – Cloud Top Albedo

$$\alpha_\lambda(z_{\mathrm{top}}) = \frac{F_\lambda^{\uparrow}(z_{\mathrm{top}})}{F_\lambda^{\downarrow}(z_{\mathrm{top}})}$$

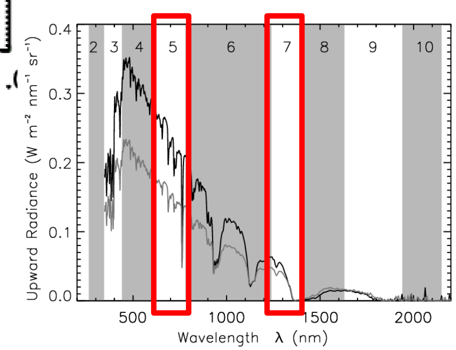




250 - 2500 nm

625 - 778 nm
(#5, scattering)

1242 -1299 nm
(#7, absorption)



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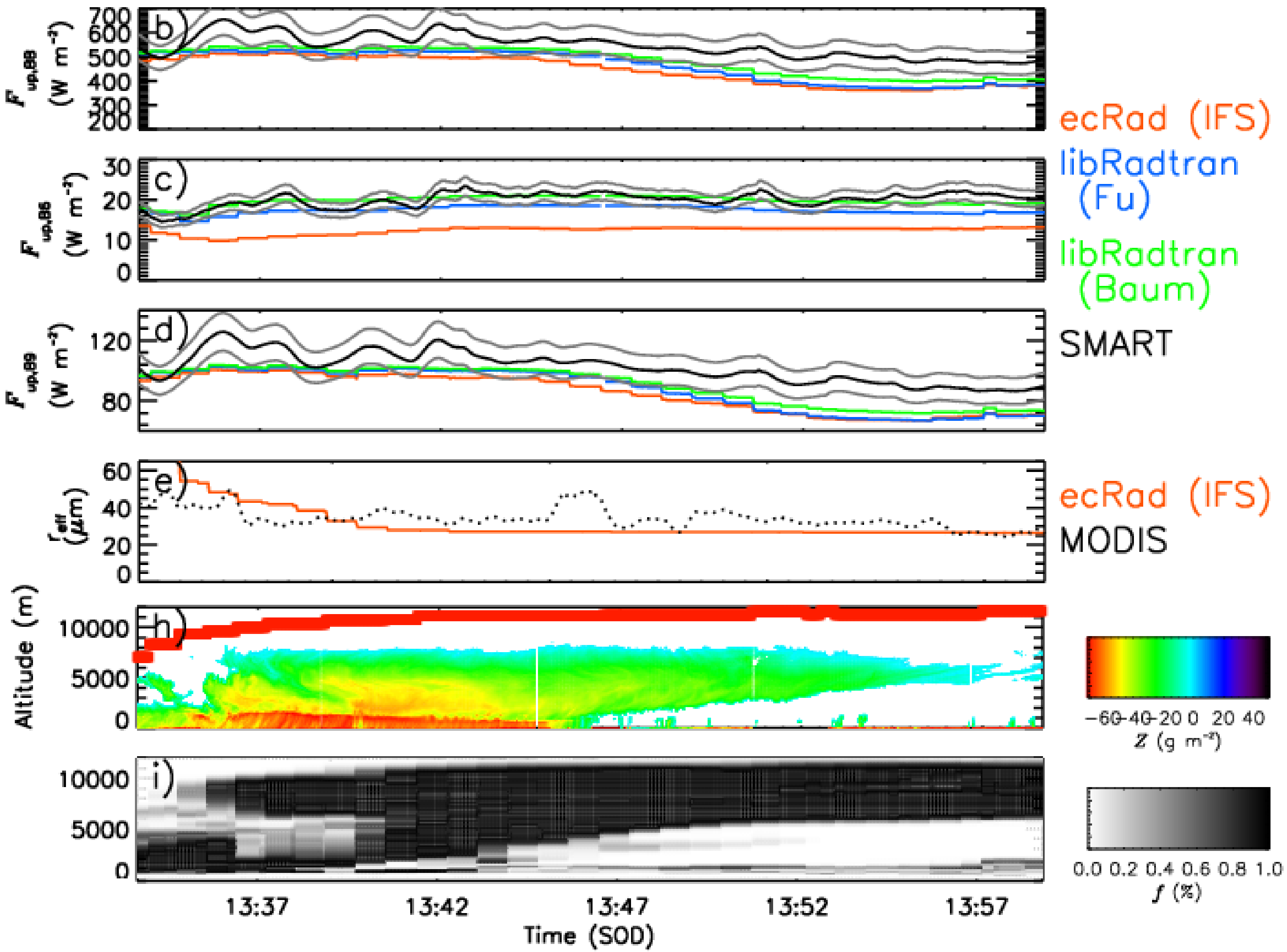
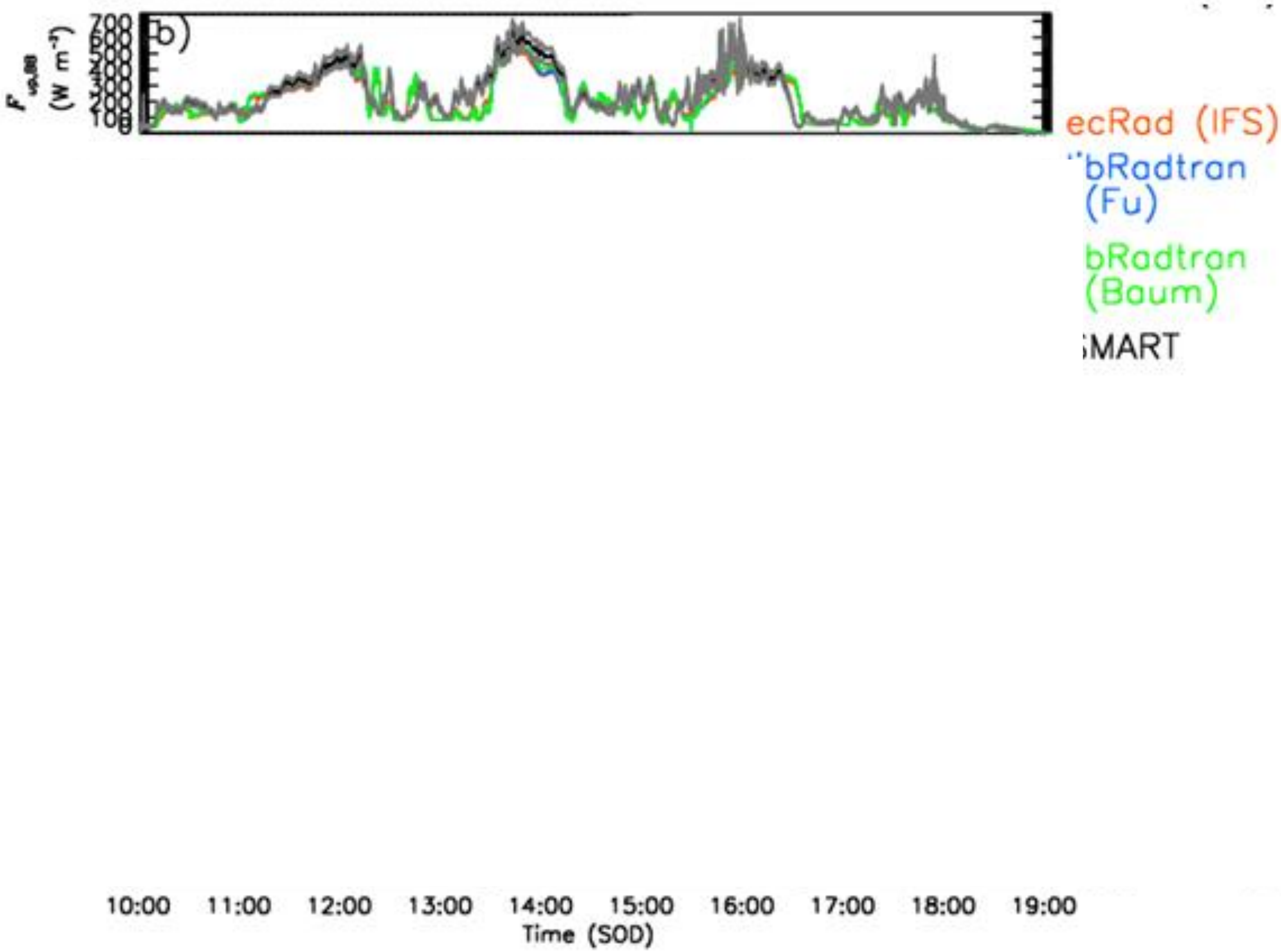
Ice Cloud Case - Timeseries



Case Study – time series



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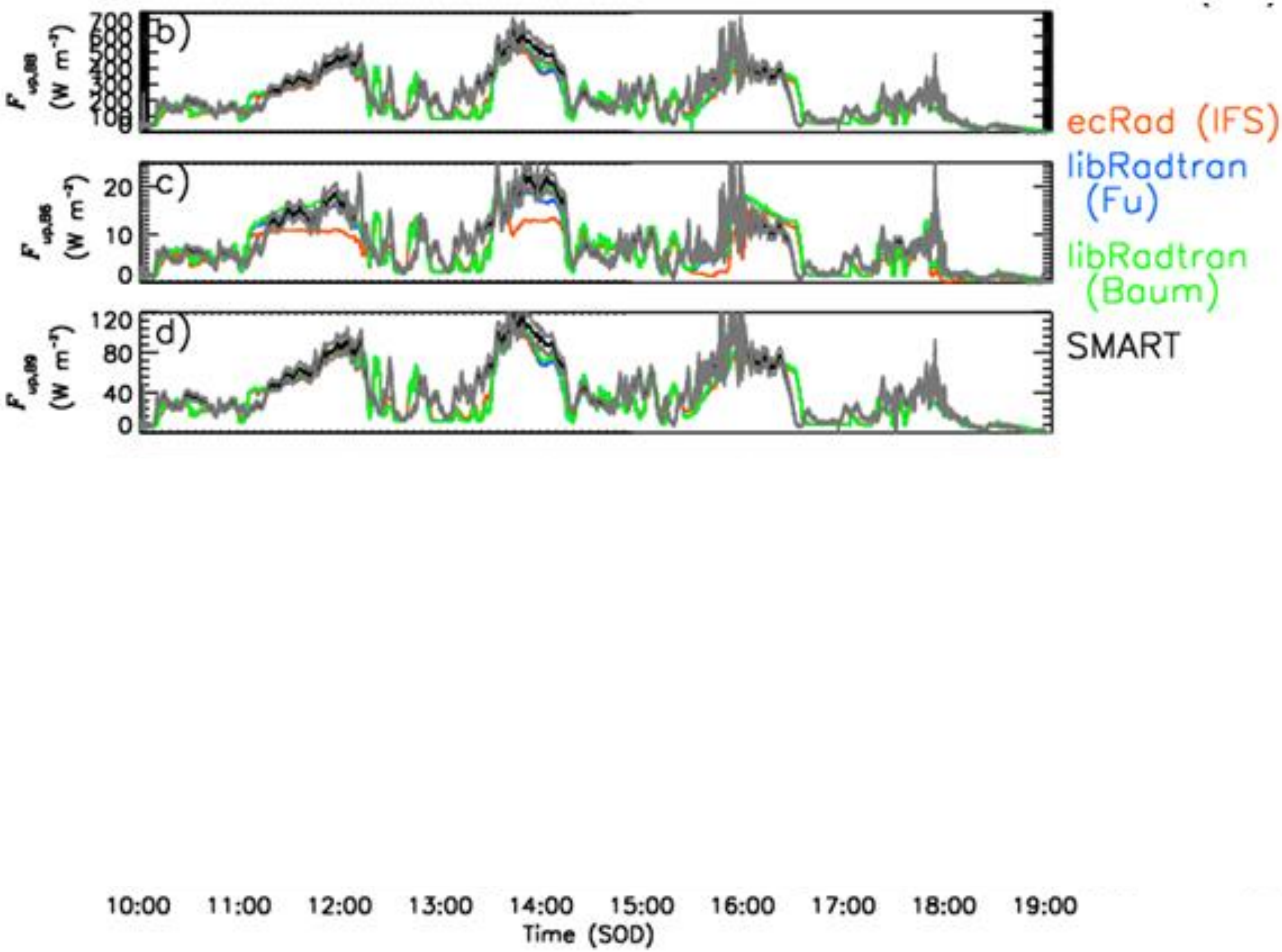
Case Study – time series



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Case Study – time series

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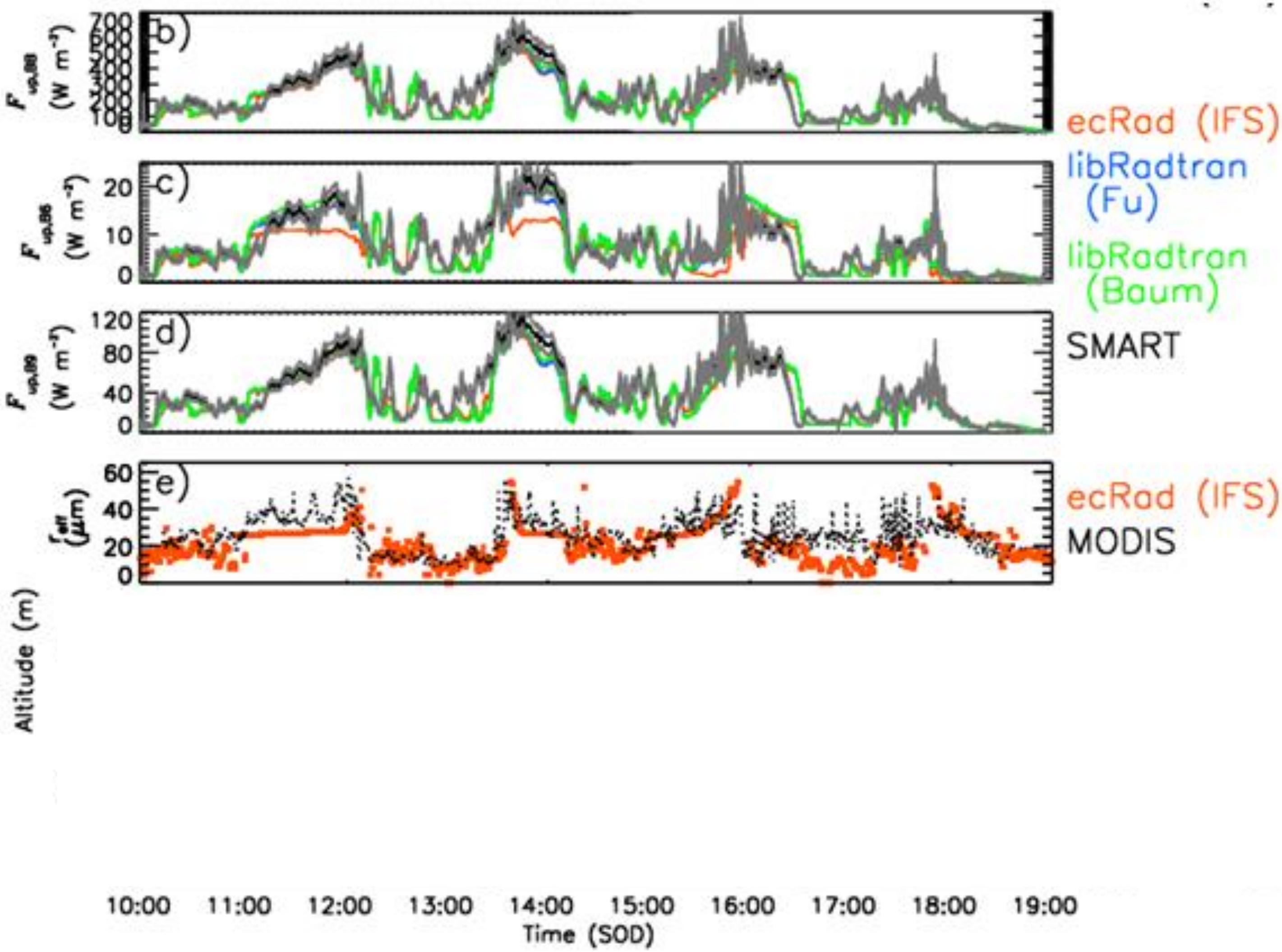

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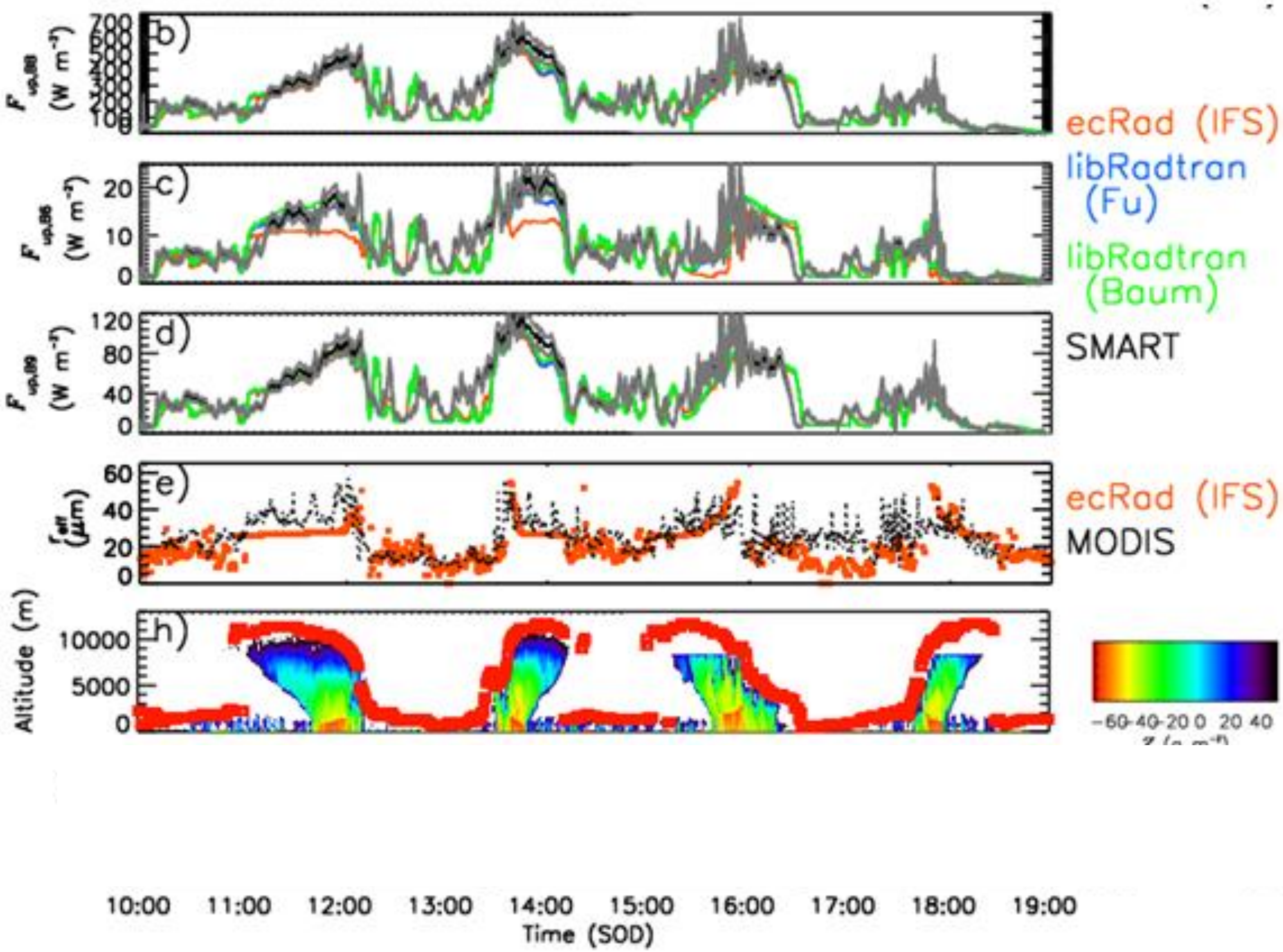
Case Study – time series



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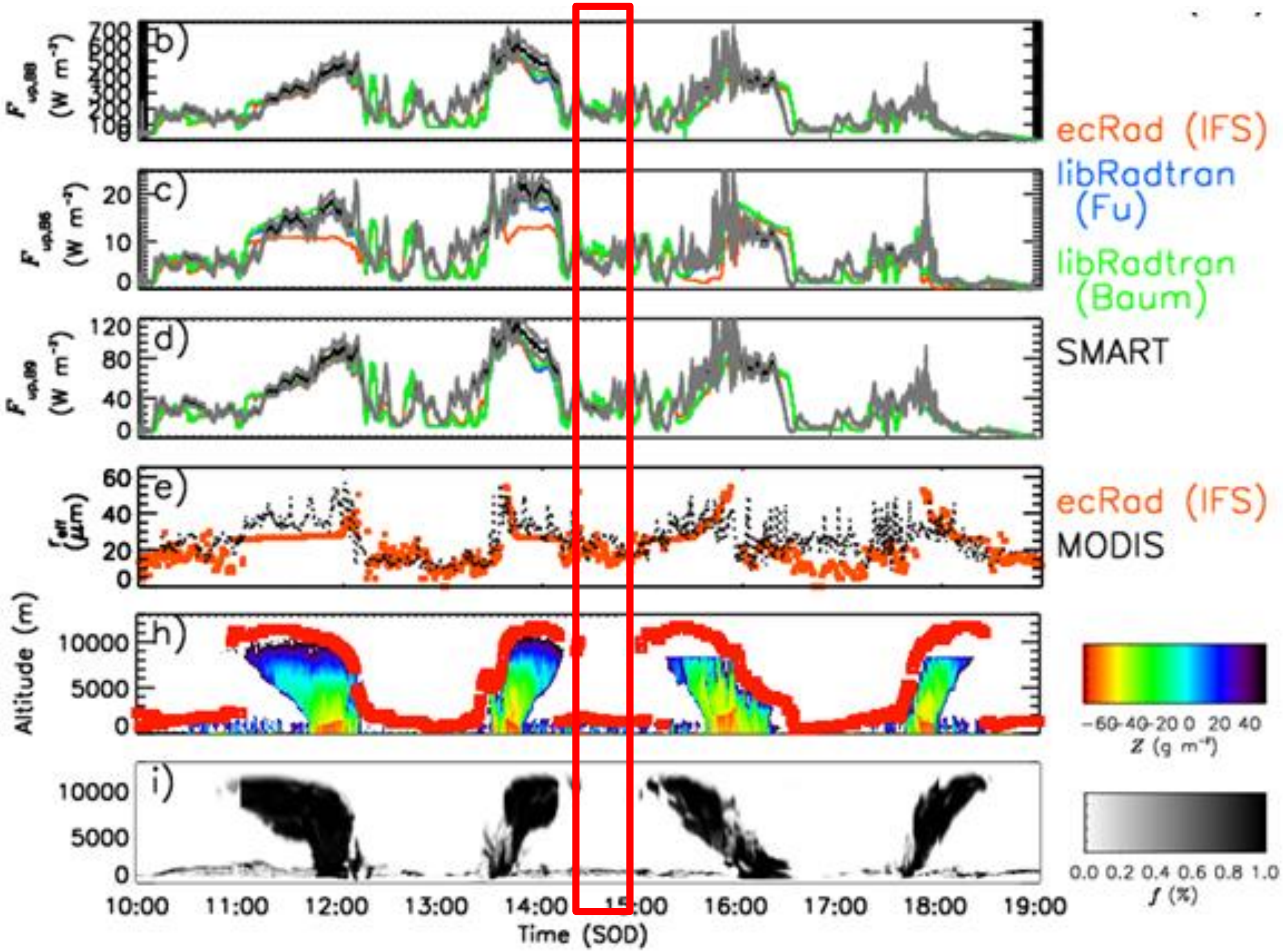
Case Study – time series

C1



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Questions to be answered

1. How to evaluate the IFS with aircraft observations?
   Application of two different RTS and compare with Observations.
   Simulation of along-track radiation and statistical comparison
2. How to identify and quantify cloud errors?
   Cloud Error: Effective radius underestimated
3. **How to identify and quantify radiation scheme errors?**
   Cloud structure represented
   Ice parameterization

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Additional slides

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Motivation – Issues in Radiation Calculations

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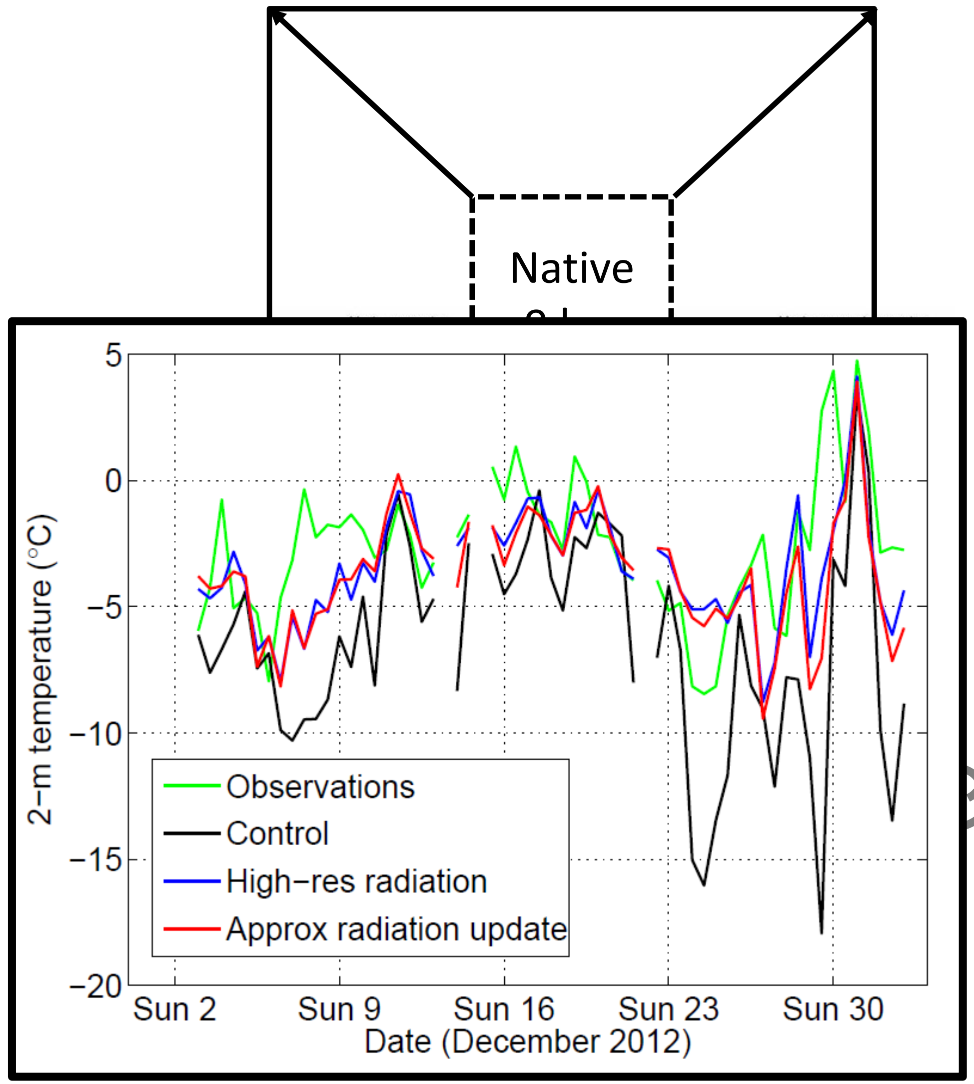
Cloud Representation Errors

- Surface Representation
  - Surface Albedo
- Aerosol Interactions
- Native Grid Resolution

Radiation Scheme Errors

- **Radiation grid resolution**
- Cloud Overlap Scheme
  - Ice crystal Parameterization



Hogan, R. J. et al., 2017

Motivation – Issues in Radiation Calculations

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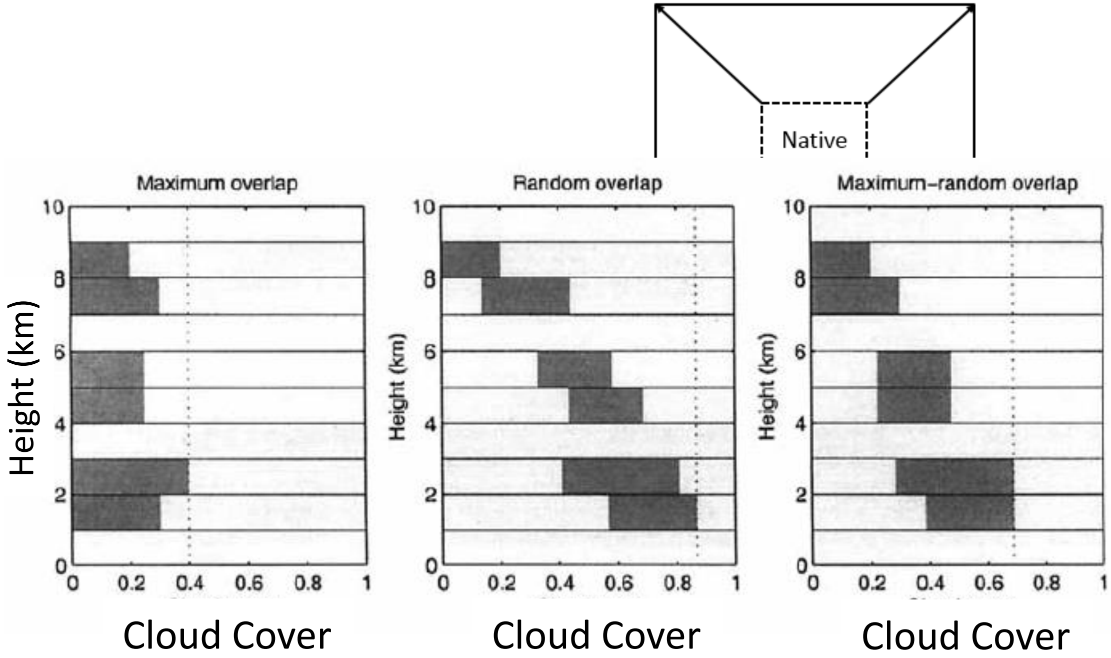
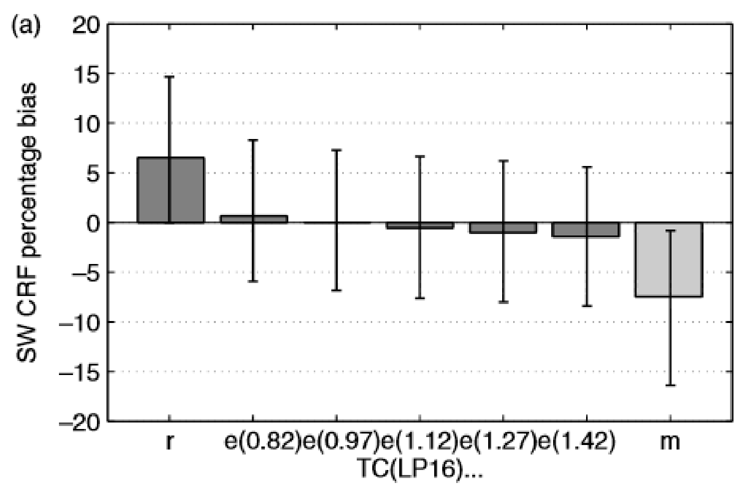
Cloud Representation Errors

- Surface Representation
  - Surface Albedo
- Aerosol Interactions
- Native Grid Resolution

Radiation Scheme Errors

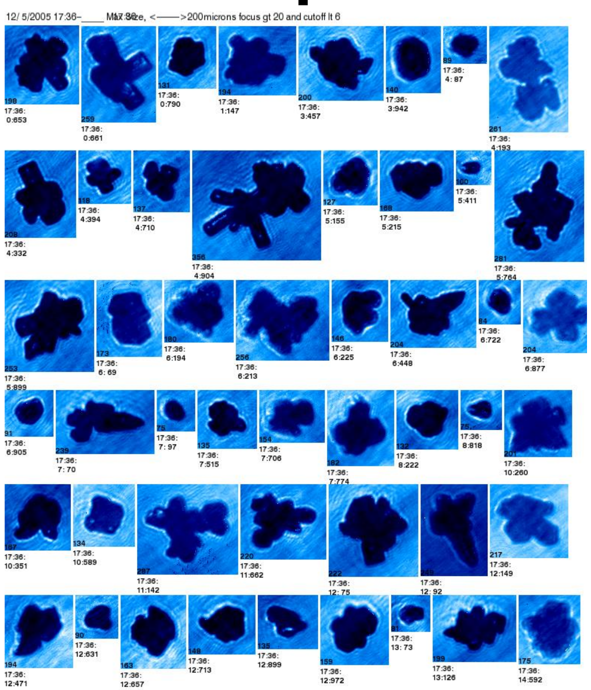
- Radiation grid resolution
- **Cloud Overlap Scheme**
  - Ice crystal Parameterization

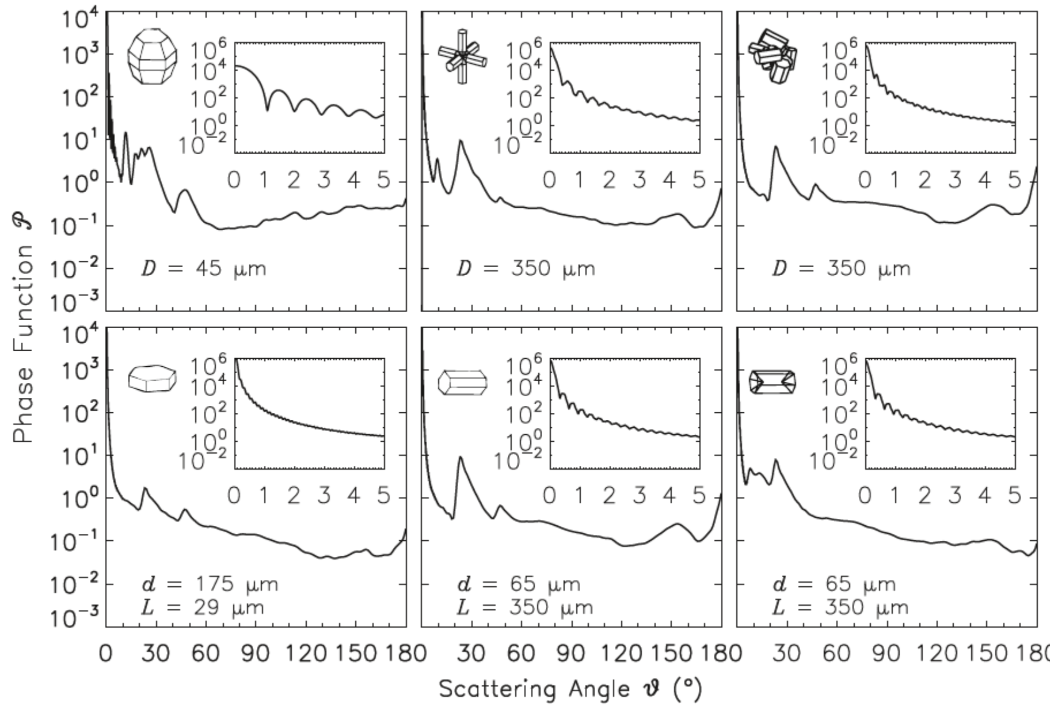


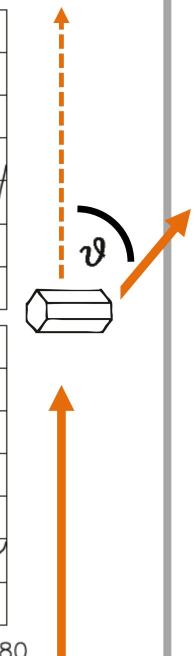


Shonk, J.K.P. et al., 2010

Motivation – Phase Function







Shape Variety:

- Formation processes
- Sedimentation
- Aggregation

Wendisch, M. and Yang, P., 2012

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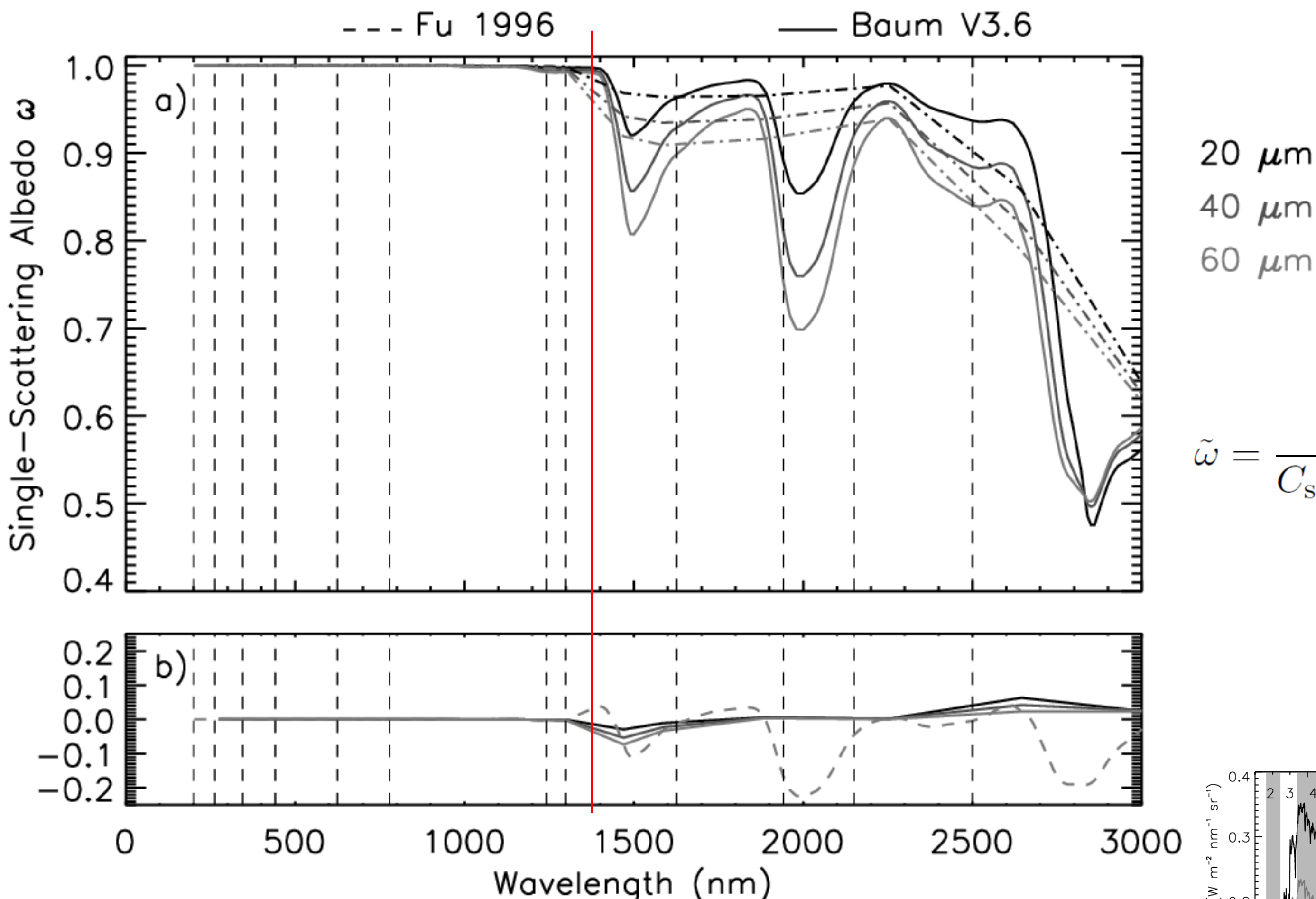
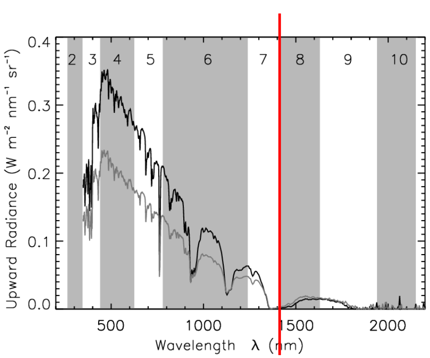
Motivation – Single Scattering Albedo



$$\tilde{\omega} = \frac{C_{\mathrm{sca}}}{C_{\mathrm{sca}} + C_{\mathrm{abs}}} = \frac{C_{\mathrm{sca}}}{C_{\mathrm{ext}}}$$



- Error < 5% for int. Signal
- Absorption -> Feedback -> Scattering

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Model Set-Up 1st step: Data Along Flight Track

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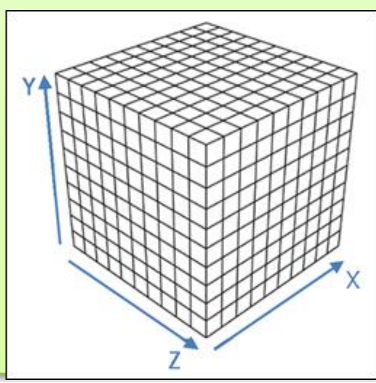
3D-Fields of Global Analysis Data

spatial resolution: 0.1°
temporal resolution: 1 h

parameters: T, Q, LWC, IWC, RWC, SWC, u, v, ω, ps, SLP, FCC, p, SKT



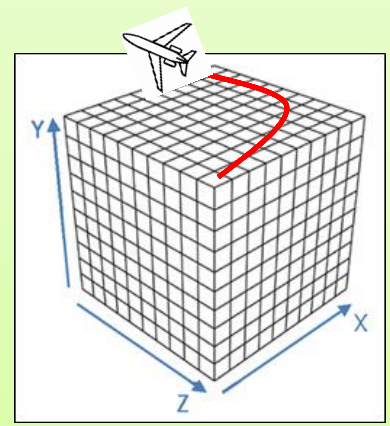
$t = 2$ s
linear temporal interpolation between hour files

interpolated spatial resolution

nearest neighbor

Vertical Columns along Flight Track

parameters: T, Q, LWC, IWC, RWC, SWC, u, v, ω, ps, SLP, FCC, p, SKT



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Instrumentation of HALO

Combination of active and passive remote sensing instruments

BAHAMAS
in-situ basic meteorology

WALES
- Differential Absorption and High Spectral Resolution Lidar

HAMP
- Microwave radiometer
- Cloud radar

SMART
- passive cloud spectrometer

specMACS
- Imaging cloud spectrometer

Dropsonde

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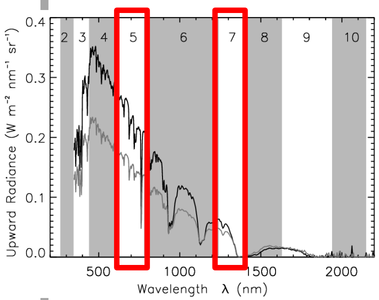
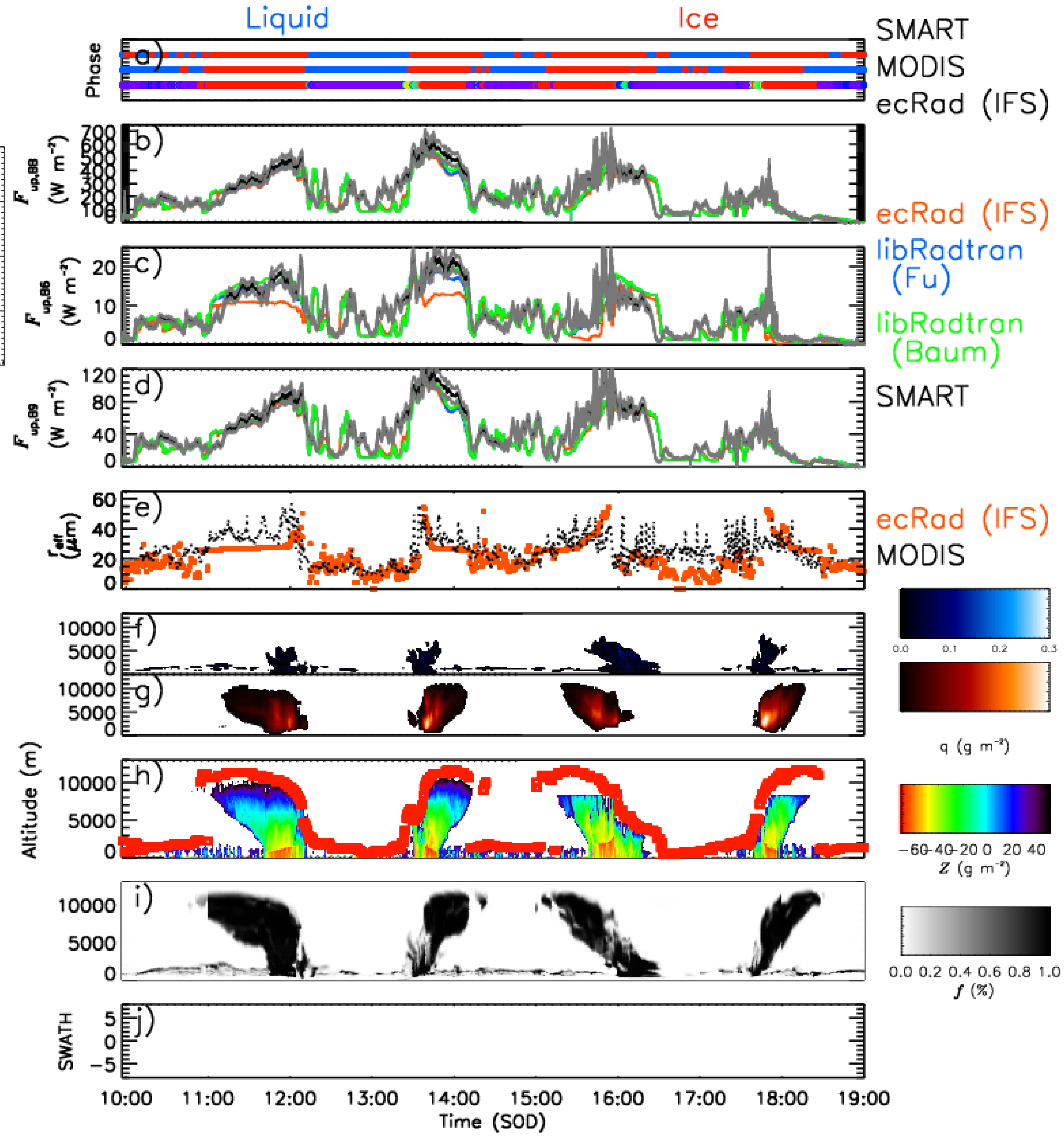
Case Study – time series





NAWDEX WS To
26-28 March 2019

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