Remote sensing of volcanic emissions using MODIS

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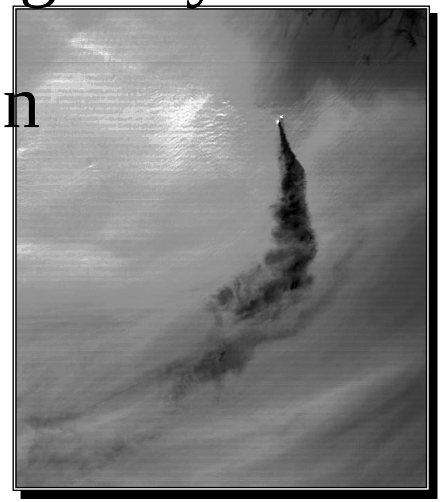
Talk structure

- Why quantify volcanic emissions?
- MODIS channels of interest
- Pre-MODIS algorithms
- Recent developments using MODIS
  - 7.34 μm channel
    - e.g. Hekla eruption (2000)
  - Forward modeling
    - Water vapor correction
- Future work
  - Species interaction (spectral)
- Conclusions

Why quantify volcanic emissions:

- Indicators of volcanic activity
- Hazardous to population, wildlife, environment and infrastructure
- Long-lived and climatologically active
- Aircraft hazard mitigation



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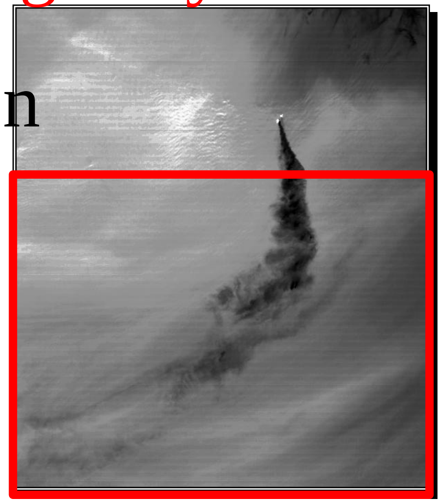
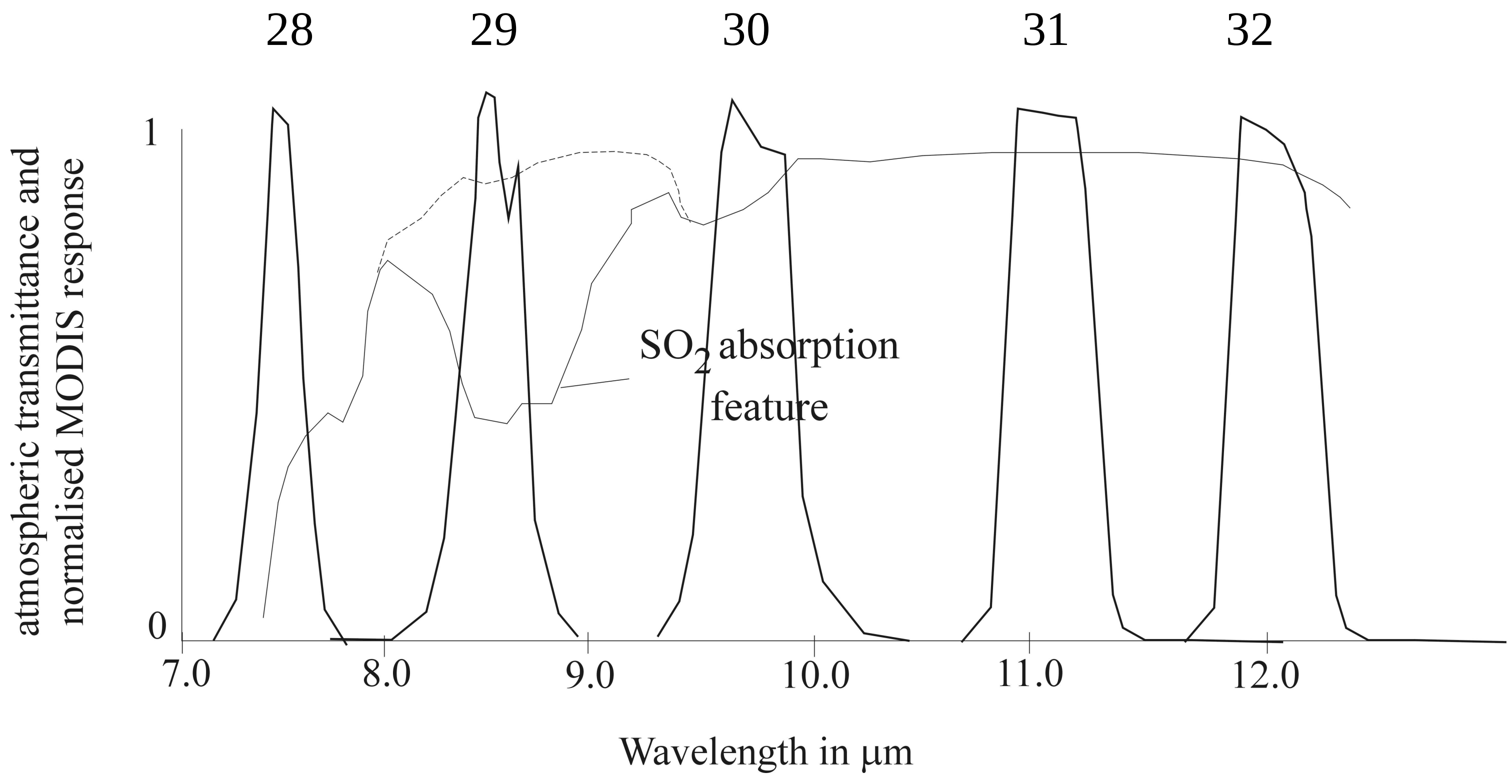



MODIS bands of interest



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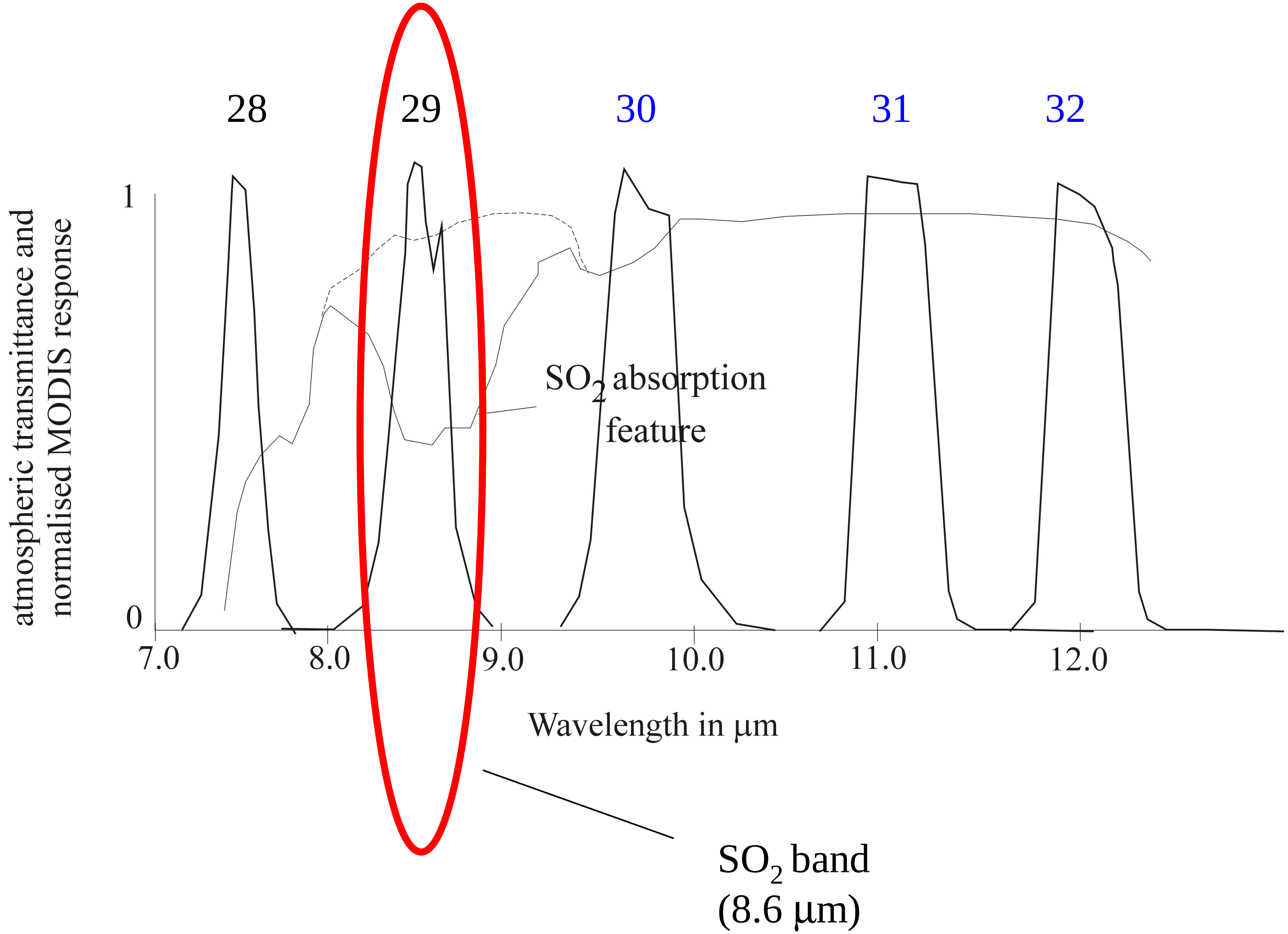

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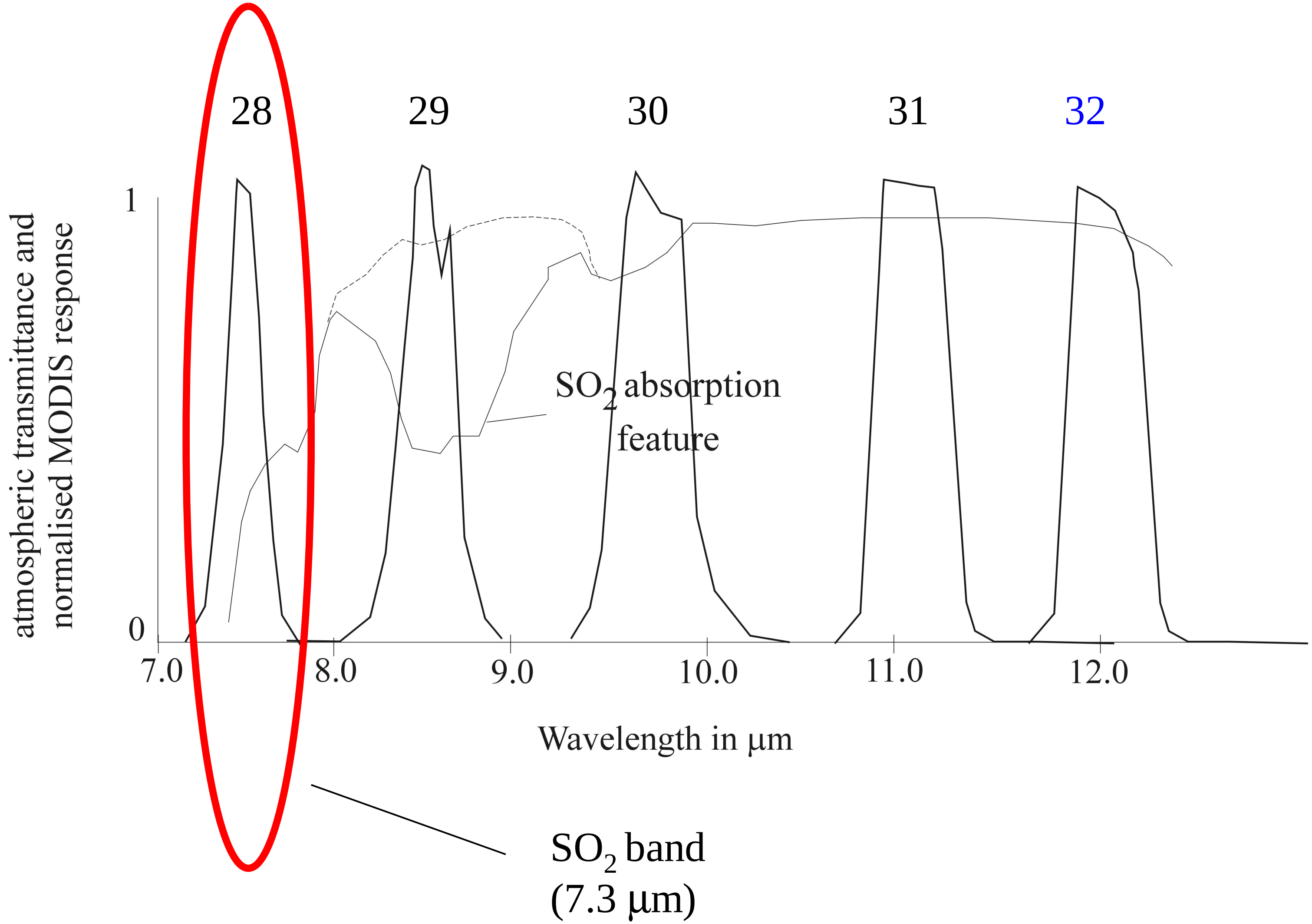

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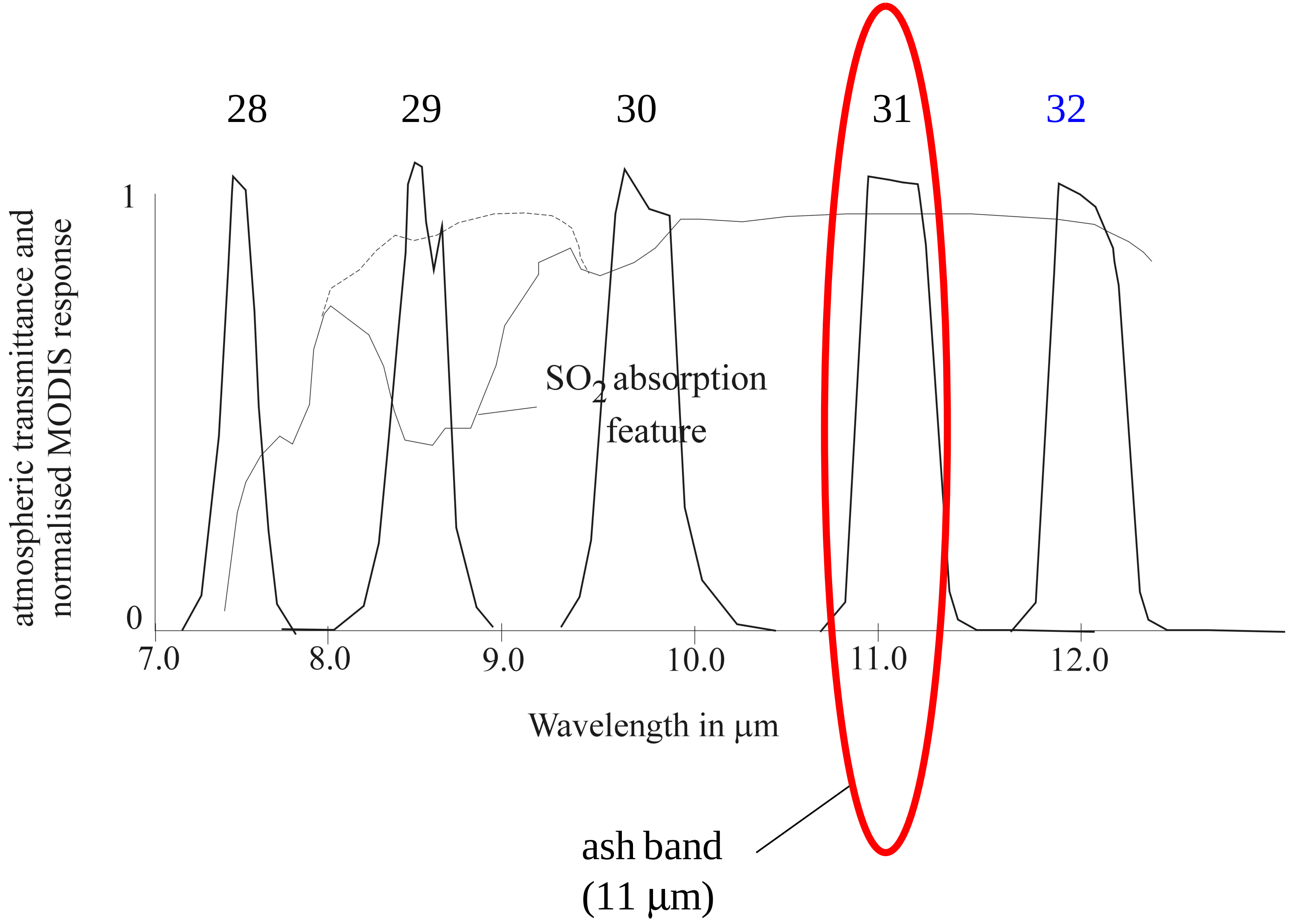

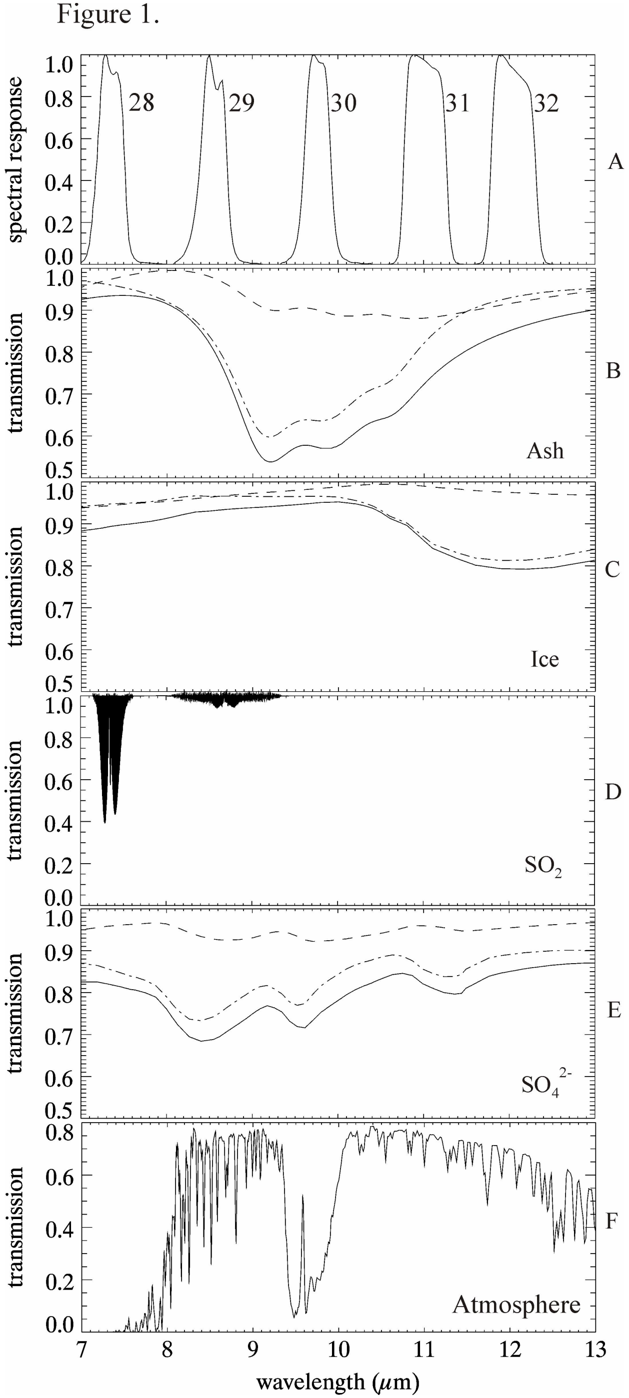

MODIS channel applications

Previous (pre-EOS) work

Species	**Original Sensor [and channels]**	**Reference**	**Year**	**MODIS channels**	**ASTER channels**	**AIRS channel sets**
Ash	AVHRR [4,5]	Prata	1989 a,b	31, 32	13, 14	12 -14
Ash	AVHRR [4,5] GOES [4,5]	Wen and Rose	1994	31, 32	13, 14	12 -14
Ice	AVHRR [4,5] GOES [4,5]	Rose et al.,	1995	31, 32	13, 14	12 -14
SO_2	TIMS [1-6]	Realmuto (et al.)	(1994), 1997, 2000	29 - 32	10-14	N/A
SO_4^{2-}	HIRS/2 [5-10]	Yu and Rose	2000	30 - 34	N/A	10-15
SO_2	TOVS[1] [8,11,12]	Prata et al.,	2003	27, 28, 31	N/A	5

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Applications of different retrievals for SO_2

Retrieval	Application	Advantages	Disadvantages
TOMS 0.3-0.36 µm	Large scale eruptions	Spectrally independent/long archive	Spatial resolution
AIRS 7.34 µm	Large scale eruptions	High spectral resolution	Spatial resolution
MODIS/ TOVS 7.34 µm	Mid scale eruptions	Climatologically active SO_2	High altitude required
MODIS/ ASTER 8.6 µm	Mid-scale – passive degassing	Monitoring possible	Ash and sulfate interference

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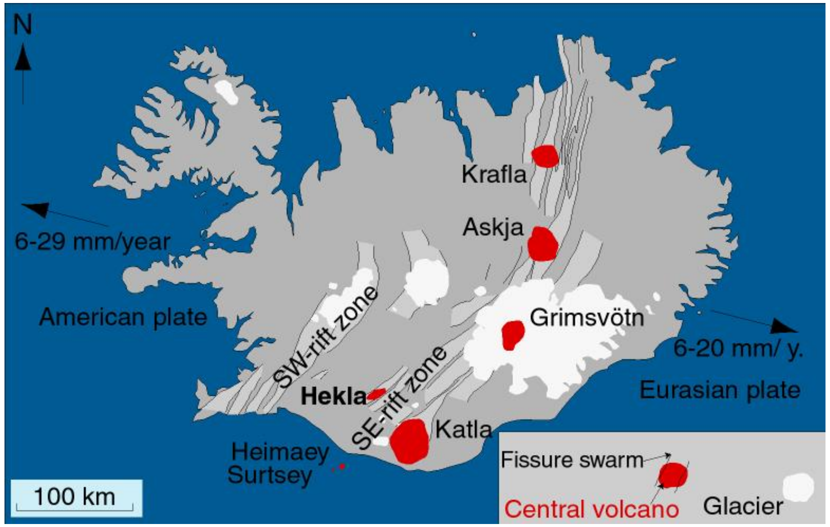
Hekla volcano, Iceland, erupted Feb 26, 2000



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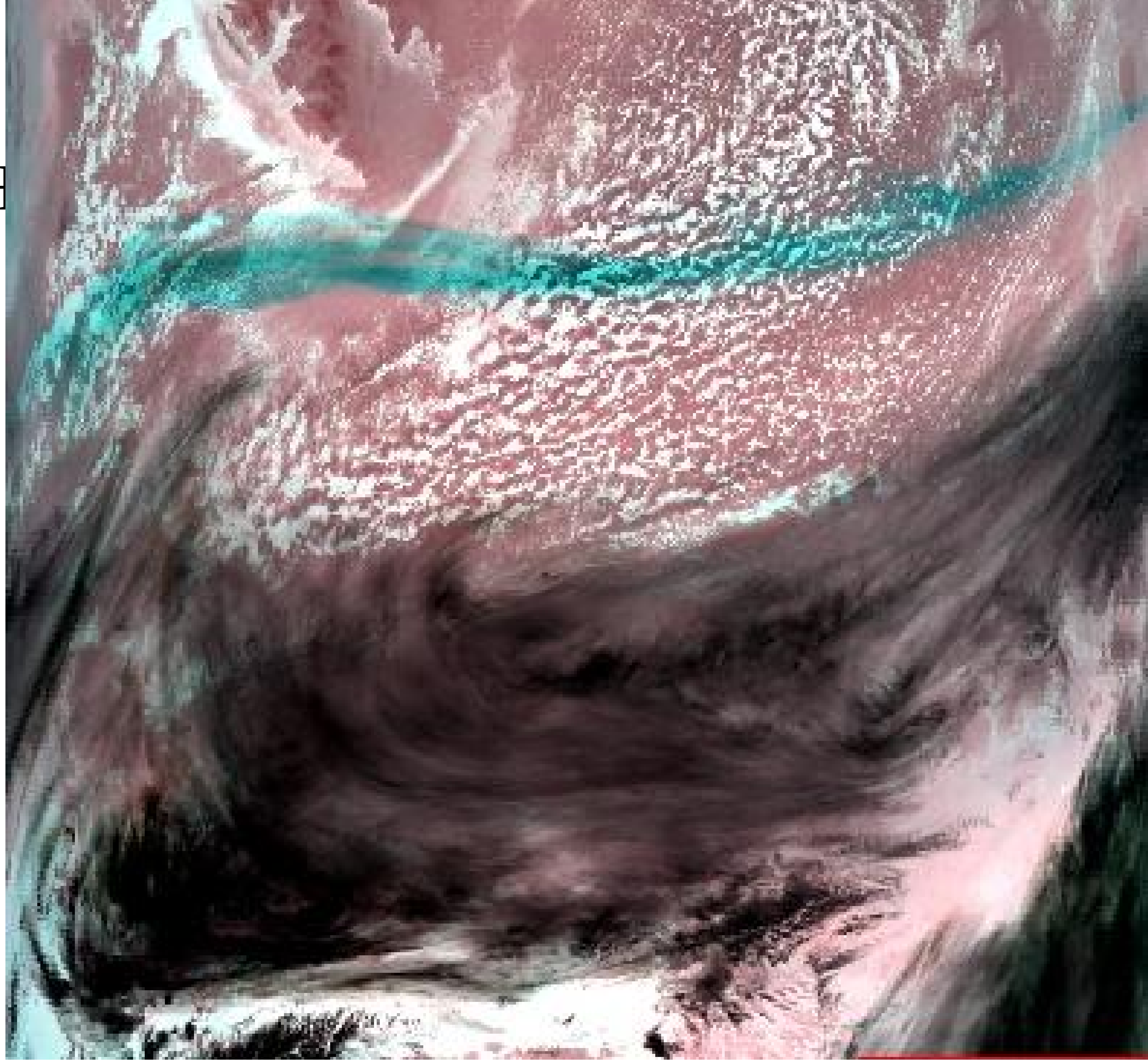
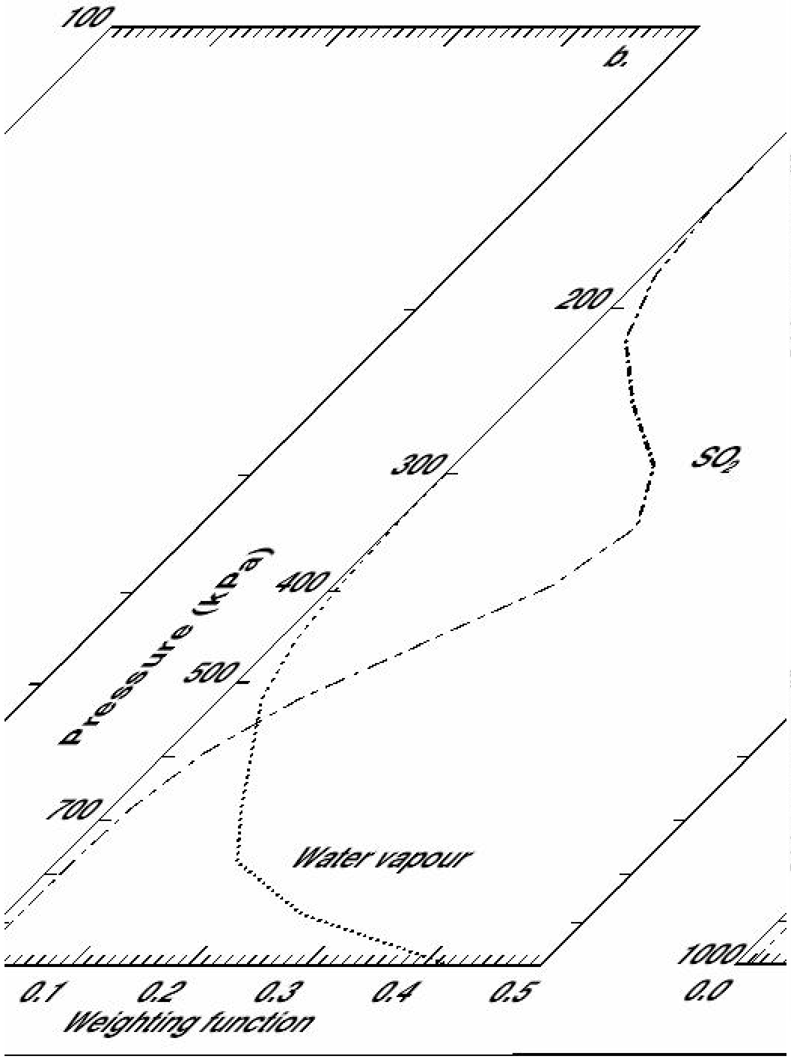
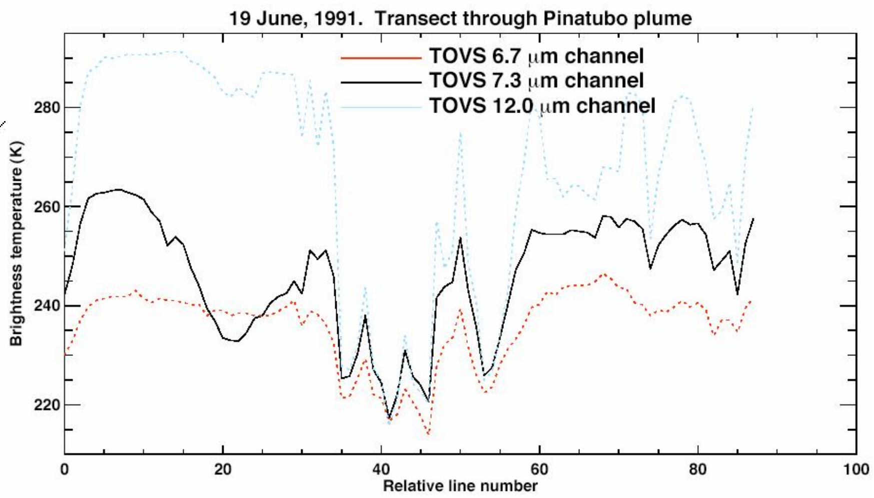
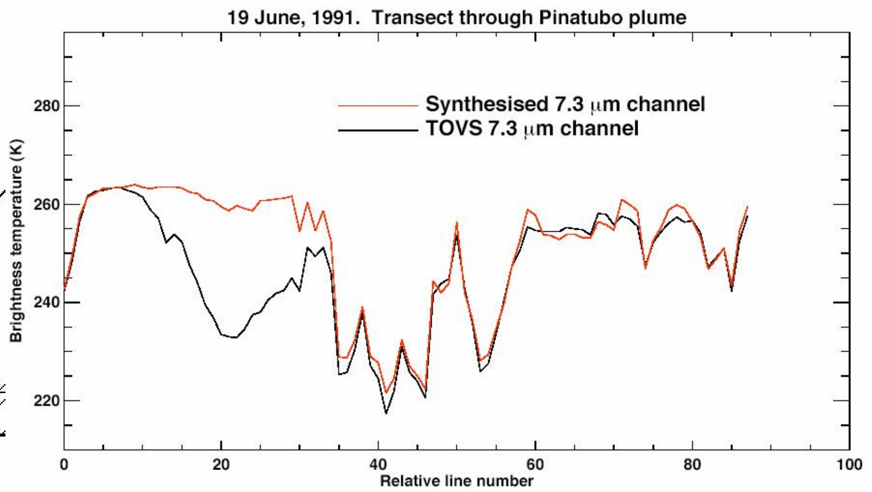
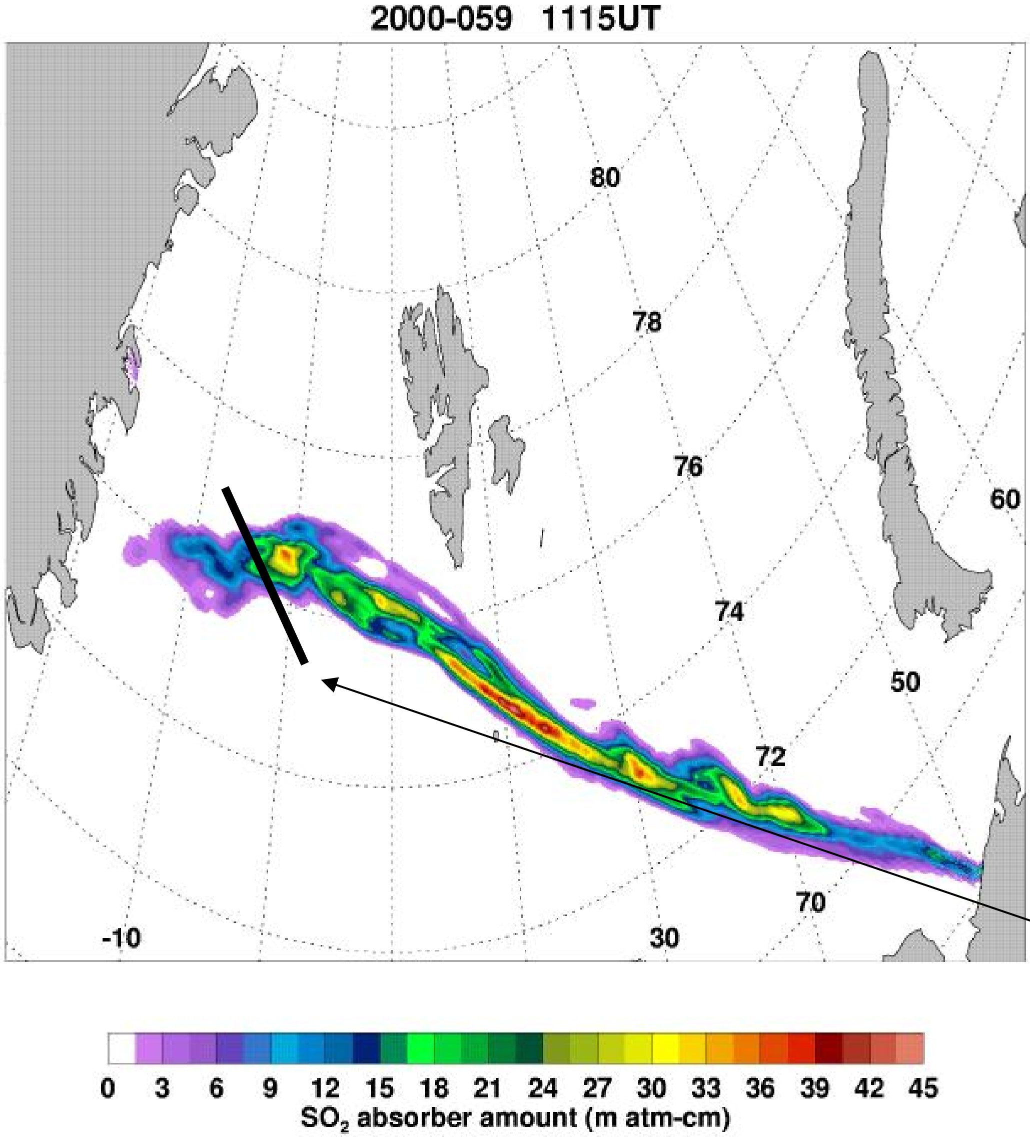


7.34 μm SO_2 retrieval - Prata et al, 2004



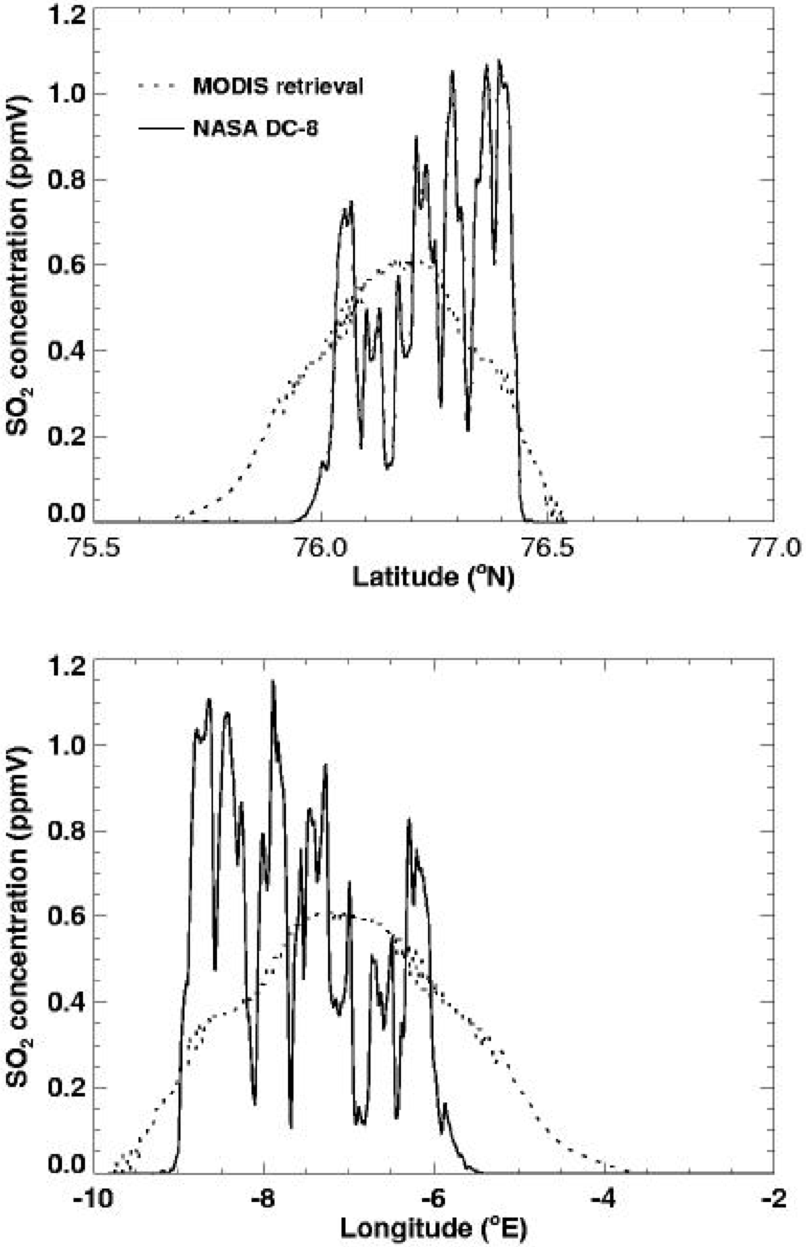






MODIS retrieval for Hekla, Feb 26 2000 eruption

Approximate aircraft track



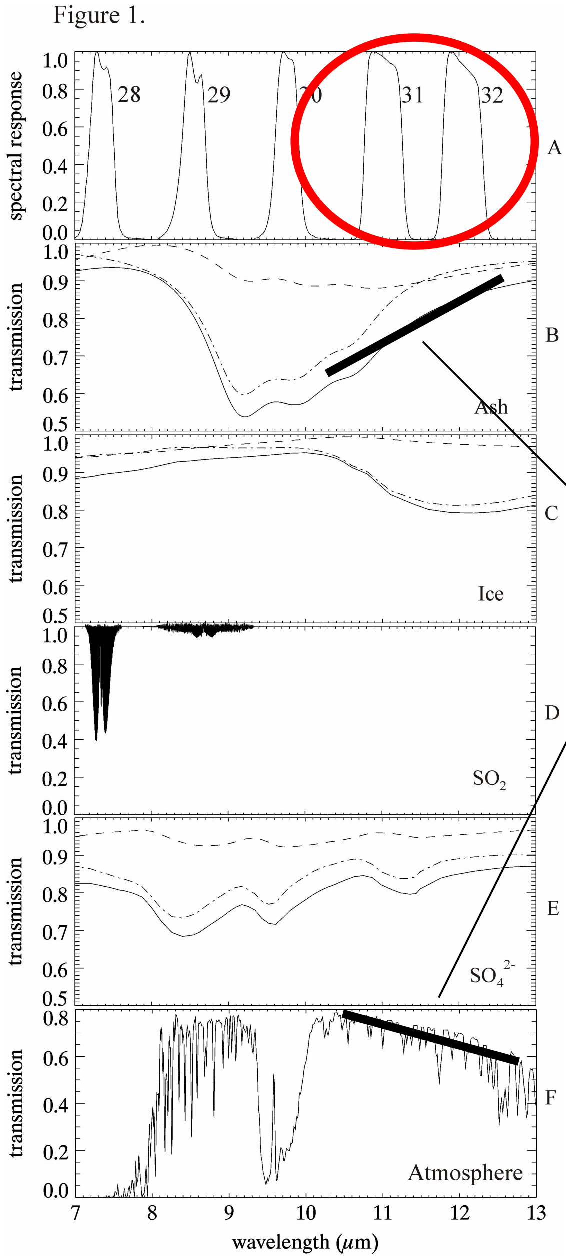
SOLVE (NASA DC-8) *in situ* SO_2 measurements and MODIS retrievals show good agreement

Integrated across plume:

SOLVE=248 ppmV

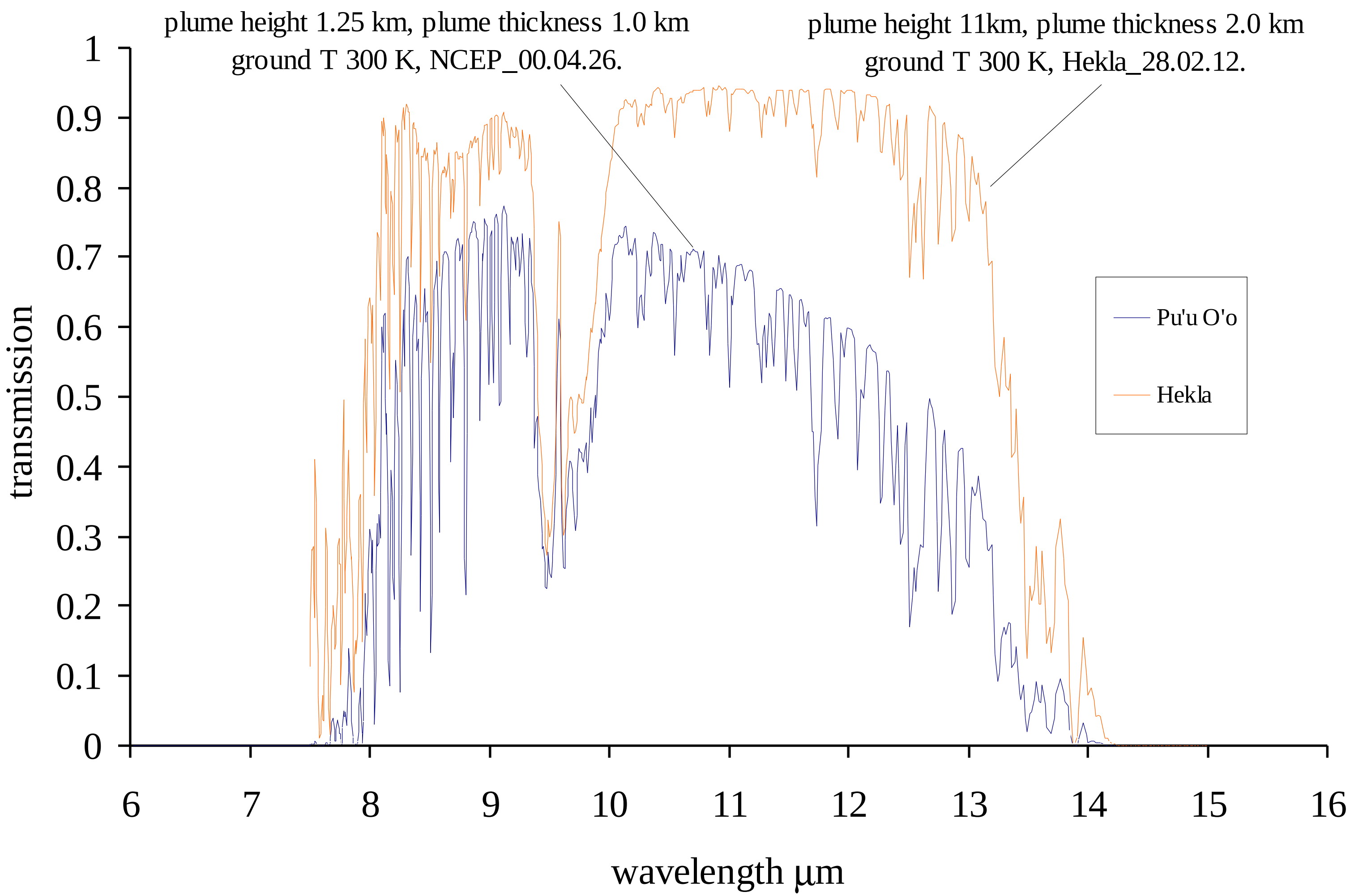
MODIS=241 ppmV

Water vapor interference



The slopes of these lines are in opposition. The 'split window' algorithm BTD (11-12 μm) is used operationally by VAACs to detect ash *and* by climatologists to map water vapor. Hence water vapor masks the ash signal.

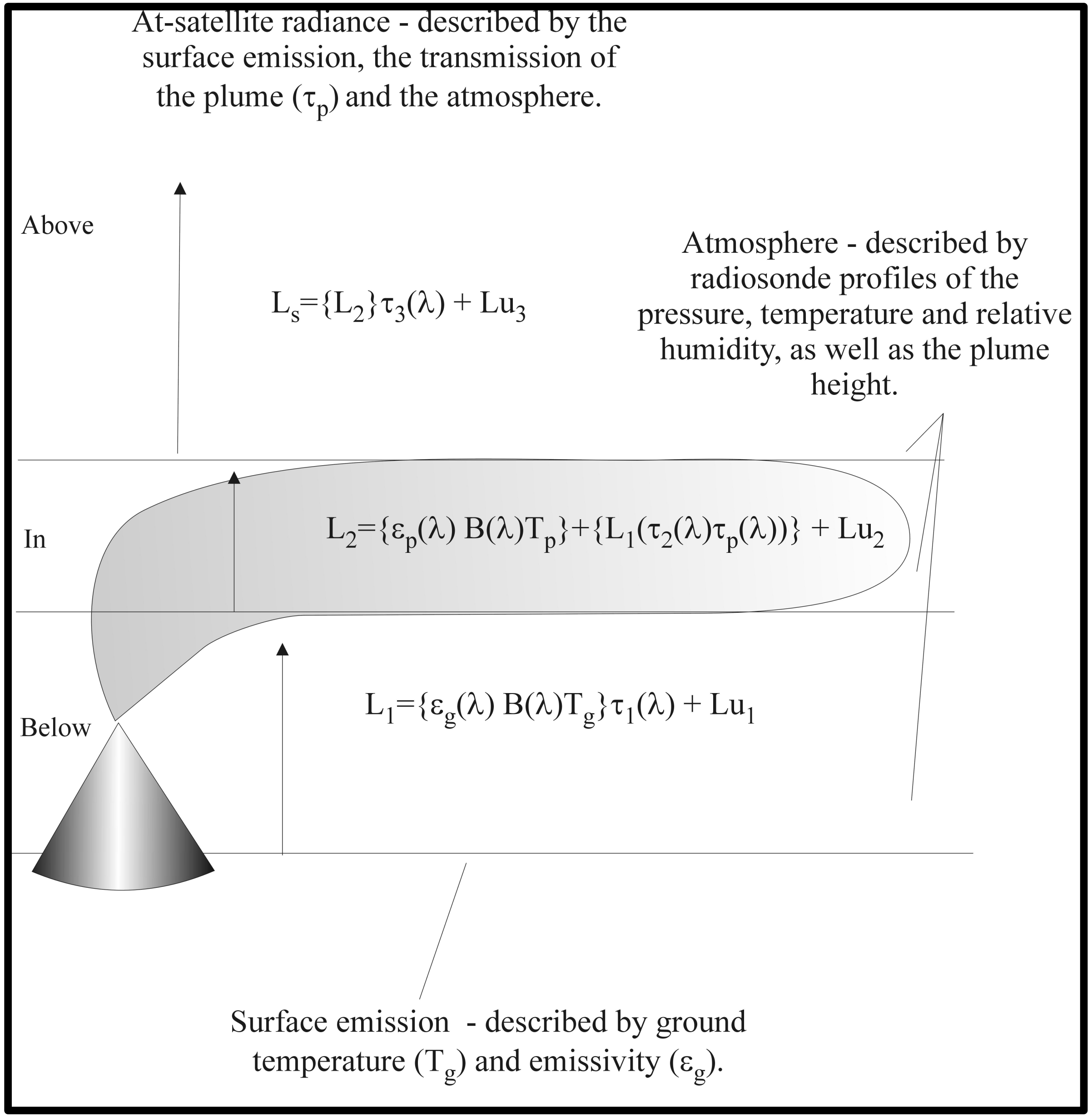
Atmospheric effects of water



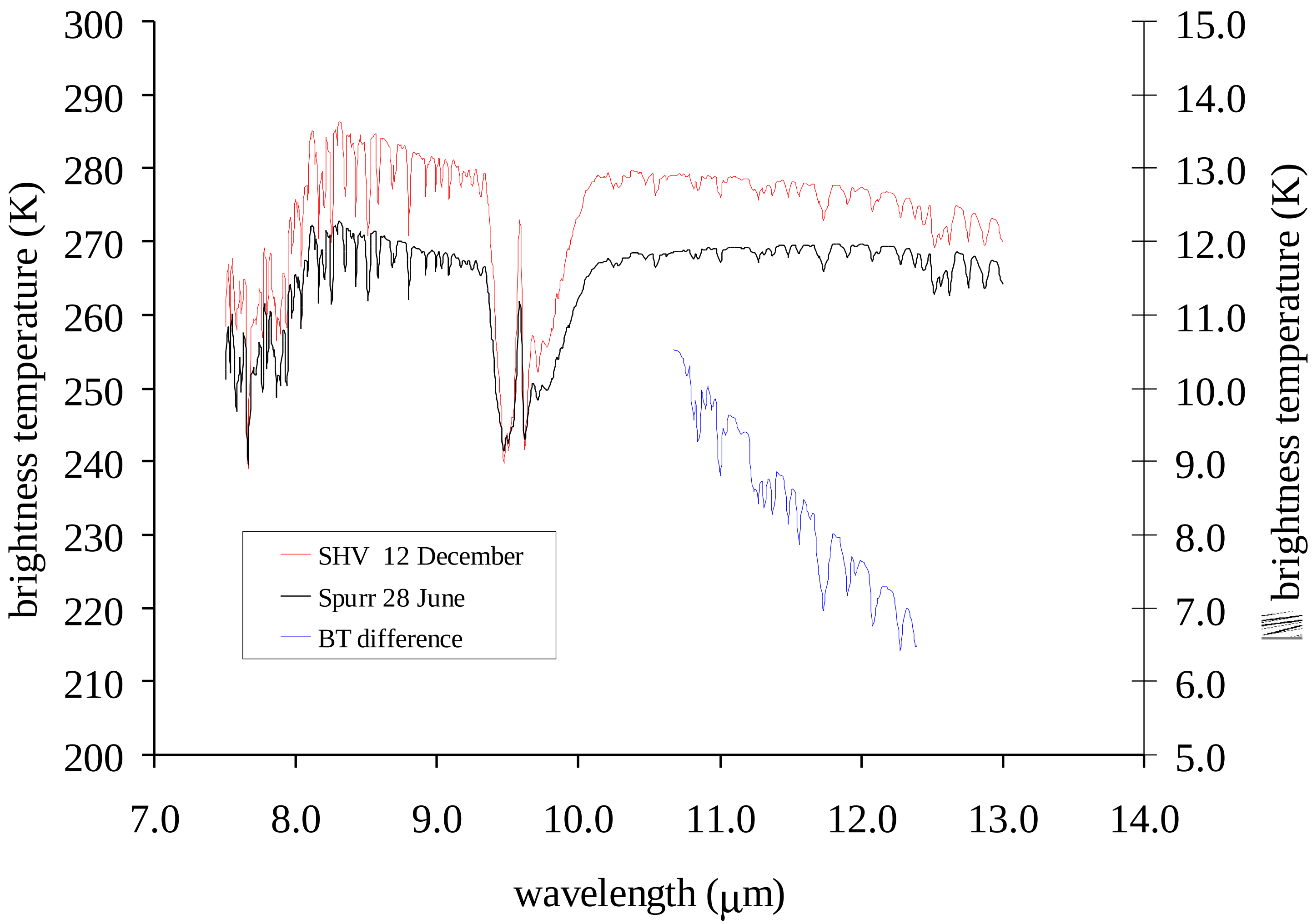
Forward model justification

- User specifies ‘external’ parameters: ground emissivity, ground temperature, atmospheric profile (water vapor, pressure and temperature as a function of height).
- User specifies ‘plume’ parameters: plume (top and base) altitude, effective radius, variance, refractive index and number density of particles
- The forward model uses MODTRAN to calculate ‘external’ effects and Mie scattering code to calculate ‘plume’ effects
- Can be used to
  - investigate atmospheric effects on IR retrievals
  - generate a LUT for multi-species spectra
  - genrate transmission spectra to be used to correct SO_2 maps for ash/sulftae

Forward model rationale



Forward model results – example spectra



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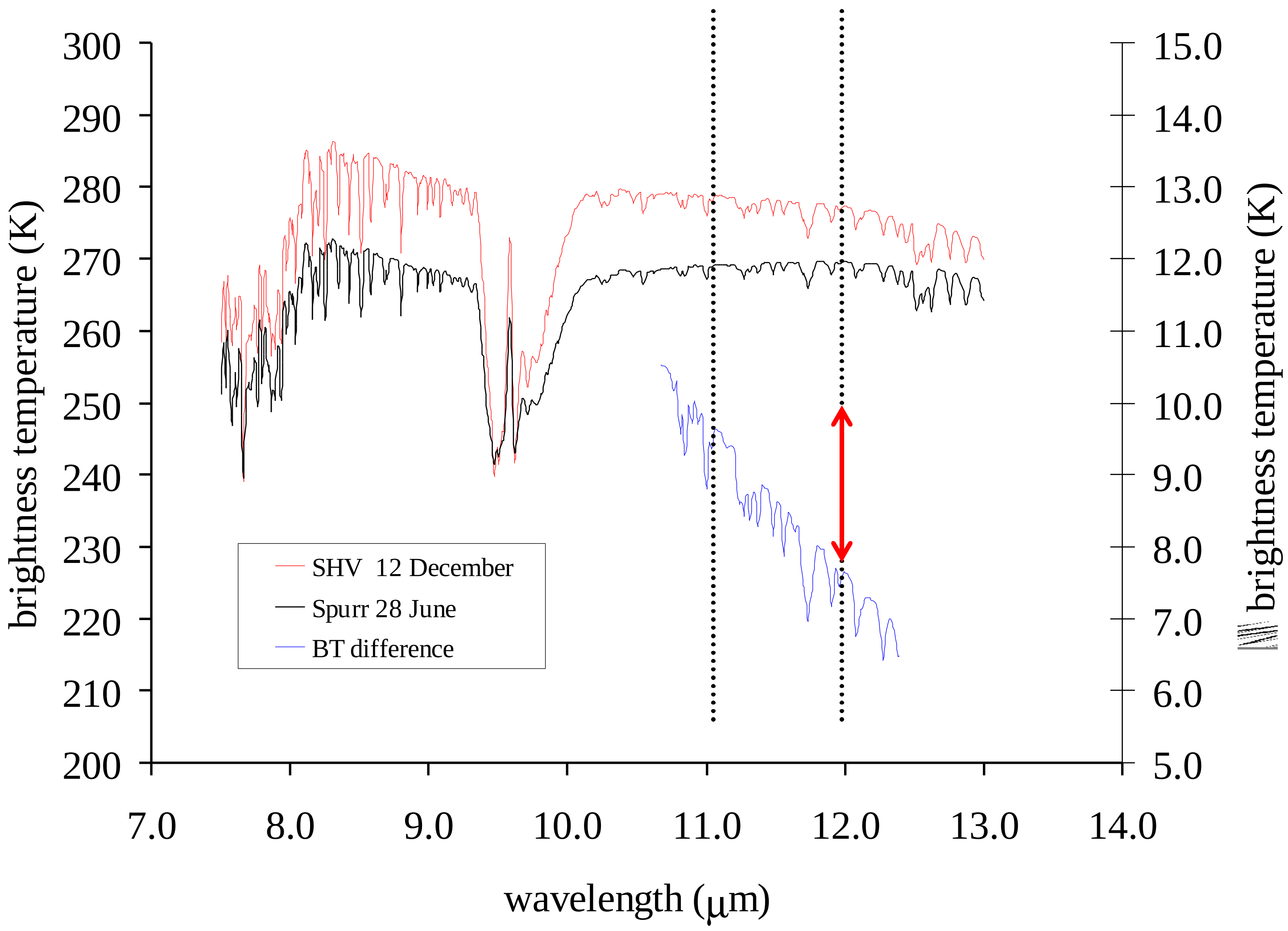
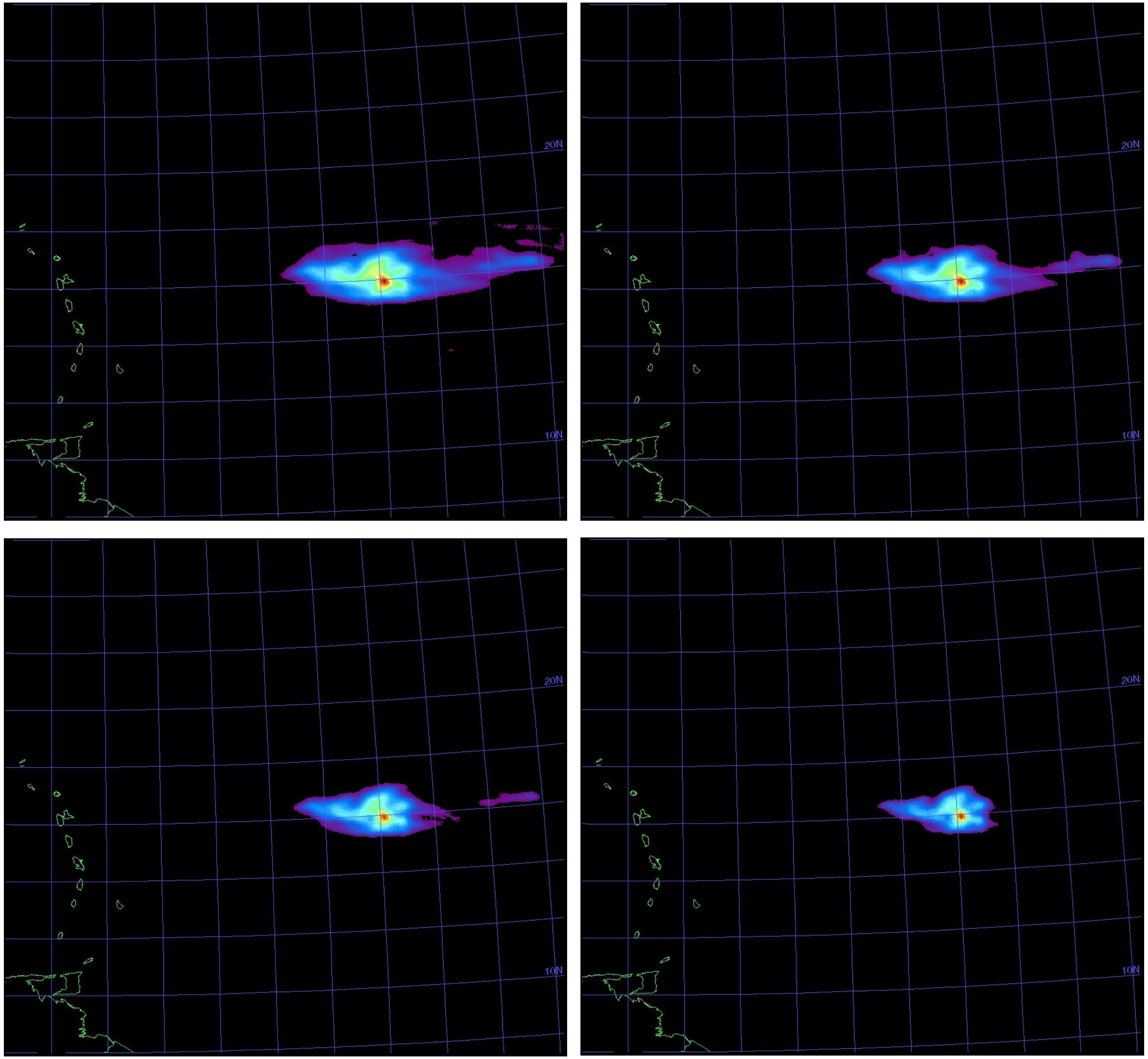


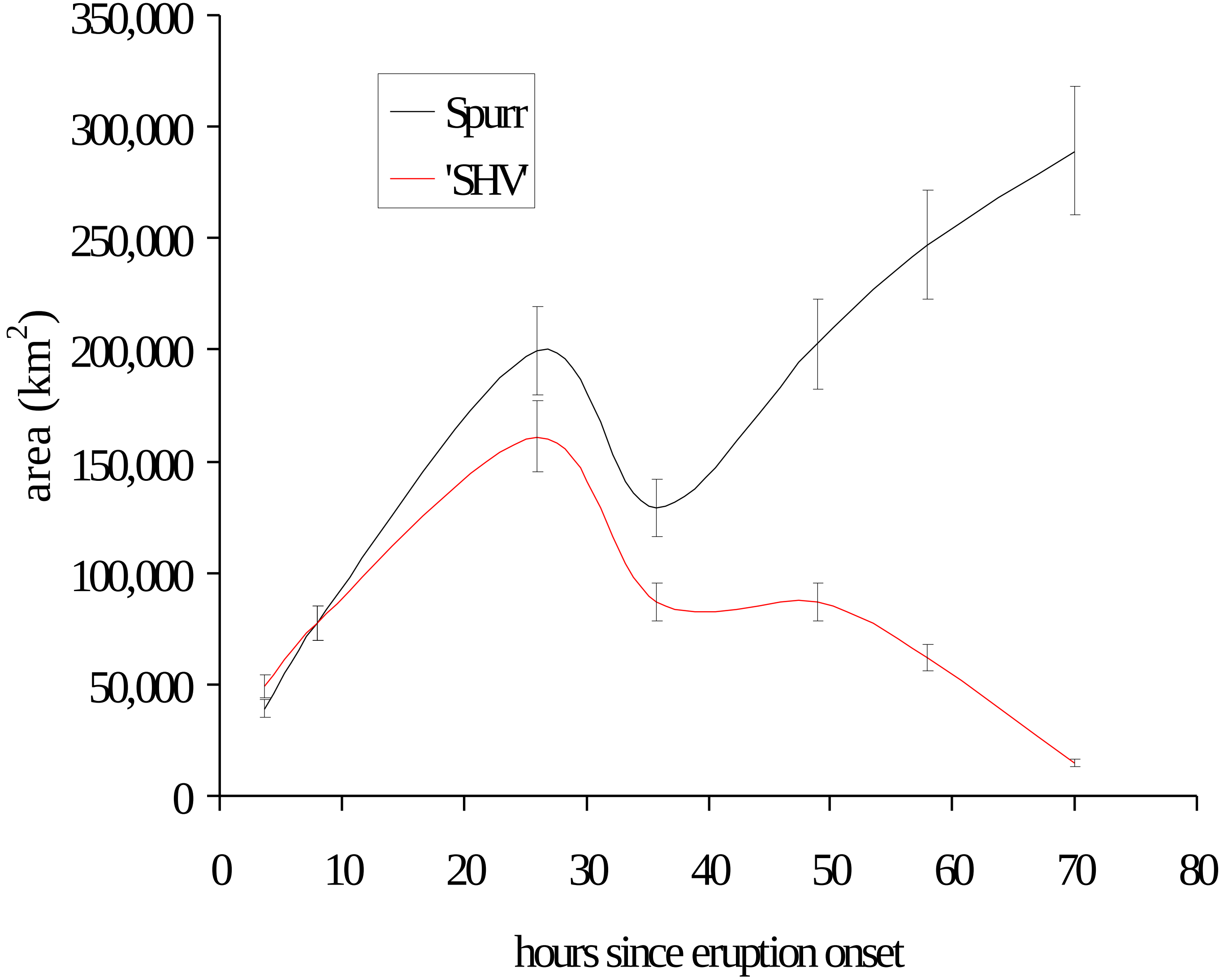
Mt. Spurr in tropical atmosphere

Brightness temperature change Δ BTD

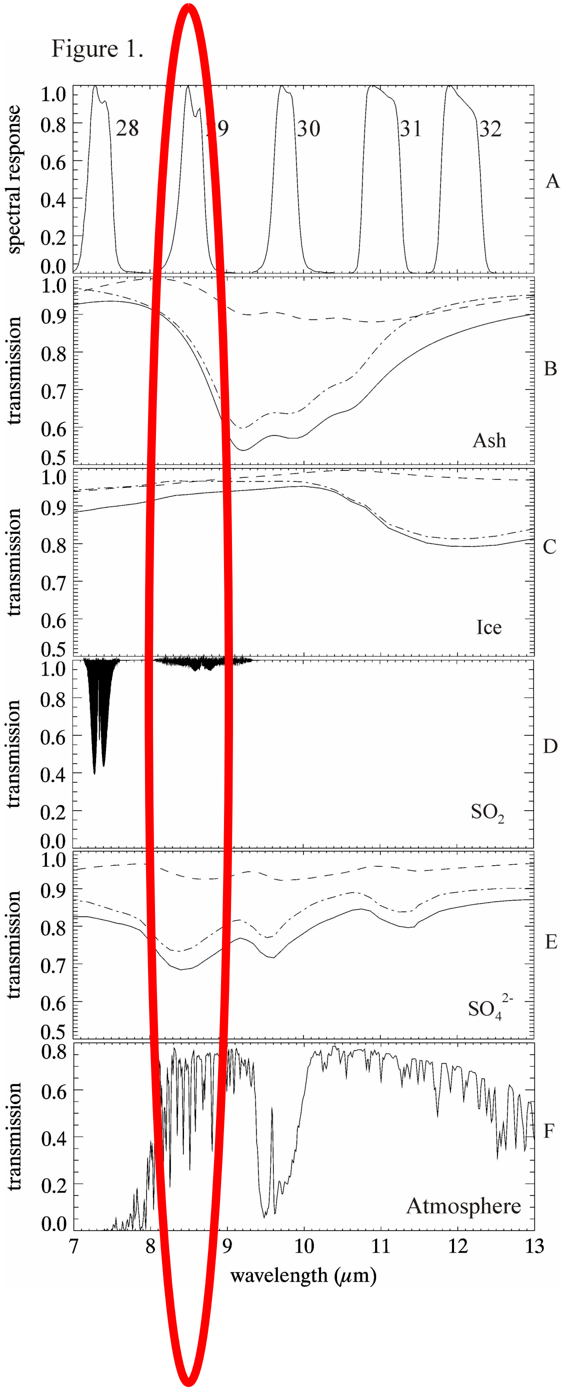
0	1
2	3



Change in cloud area caused by water vapor interference



Species Interference



3 μm andesite

5 μm ice

10 g m^{-2} SO_2

0.5 μm 75 % H_2SO_4

Mid-lat atmosphere

Multi-species algorithm development

- Volcanic emissions group (3 professors, 5 PhD students and 2 MS students at two universities) working on various parts of the problem.
- Empircal and theoretical approaches used
  - Looking at examples of ash-SO_2 separation (e.g. Anatahan 2003)
  - Forward modeling of multispecies clouds
  - Correction of SO_2 for ash and sulfate
  - Multi-sensor comparisons (TOMS, AIRS, TOVS, ASTER)
- Several eruptions targeted, work in progress

Conclusions

- The development of the 7.3 μm algorithm has been a significant advance in quantifying volcanic SO_2 (limited species interaction, works at night).
- Hekla-DC8 interaction provides unprecedented ground-truthing opportunity.
- Forward modeling can be used to quantitatively determine the effects of different water vapor concentrations on the ‘split-window’ signal.
- Water vapor more strongly affects clouds that are optically thinner as relative proportions of signal from the underlying ground (and water vapor) increase.
- A multi-species algorithm is the holy grail of volcanic emission remote sensing. Only through MODIS’s ability to detect and quantify more than one species has the problem been (a) illuminated and (b) potentially solvable.