CERES SSF TOA Fluxes over Volcanic Ash Plumes with MODIS Ash Detection

GFDL CERES/GERB/ScaRaB Science Team Meeting

David Fillmore [1] and David Kindig [1]

[1]Tech-X Corporation http://www.txcorp.com

fillmore@txcorp.com

2012 October 22 - 25

Motivation

Improve CERES SARB TOA and surface flux calculations [3] through improvements to:

1. Aerosol type identification (MODIS or VIIRS multi-channel algorithms)
2. Aerosol vertical profile (CALIOP lidar)

Focus on natural events such as:

1. Dust storms
2. Wildfire smoke
3. Volcanic ash plumes (intense, highly localized sources [11])

Figure 1 : Puyehue eruption, Chile, 2011 June 5. *Photo credit Alvaro Vidal, Getty Images.*

Remark: Volcanic climate forcing is due to SO_2 emissions (stratospheric SO_4), the effect of ash particles on the global energy balance is negligible. High SO_2 plume concentrations can be detected in the UV spectra of instruments such as Aura OMI.

Overview

1. Identify volcanic ash clouds with multi-channel MODIS ([10]) algorithms
2. Plume heights taken from auxillary sources
3. Temperature profiles from MERRA
4. Estimate ash optical depth from MODIS visible channel reflectances with radiative transfer model (libRadtran)
5. Compute SW, LW, WN TOA fluxes ([7]) at SSF level with radiative transfer model
6. Compare to instantaneous CERES SSF fluxes ([6], [5], [4])

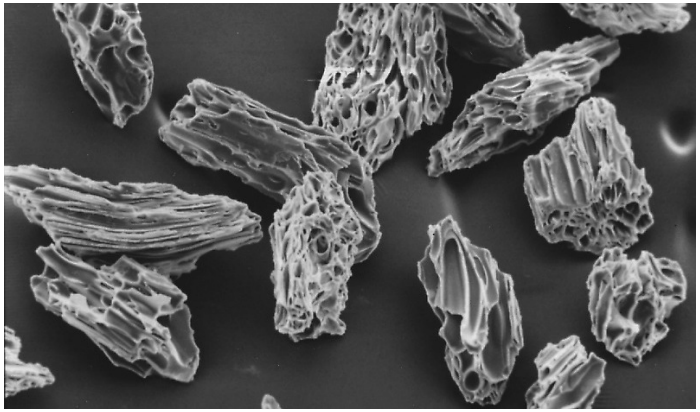


Figure 2 : SEM image of large ($D \sim 100\mu\mathrm{m}$) andesite shards (volcanic glass), *USGS*.

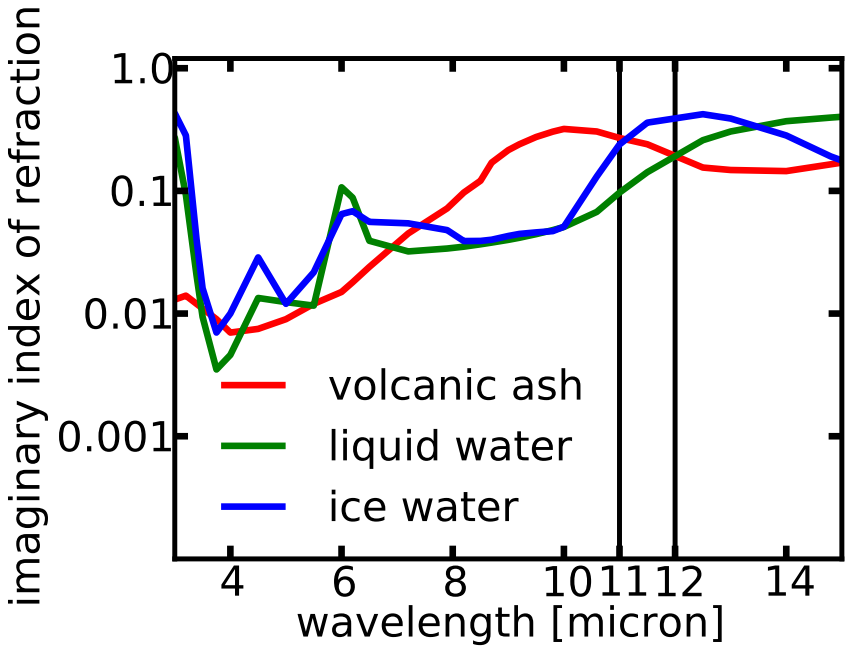


Figure 3 : Imaginary part of the index of refraction versus wavelength for volcanic ash (red), liquid water (green) and ice water (blue) (HITRAN 2008).

Mie scattering, log-normal size distribution with $r_e = 2.4\mu\mathrm{m}$. See Muñoz [8] for scattering calculations.

Split Window Ash Detection BTD(11-12) < 0

Modified Pavolonis algorithm ([2], [9], [12], [13]).

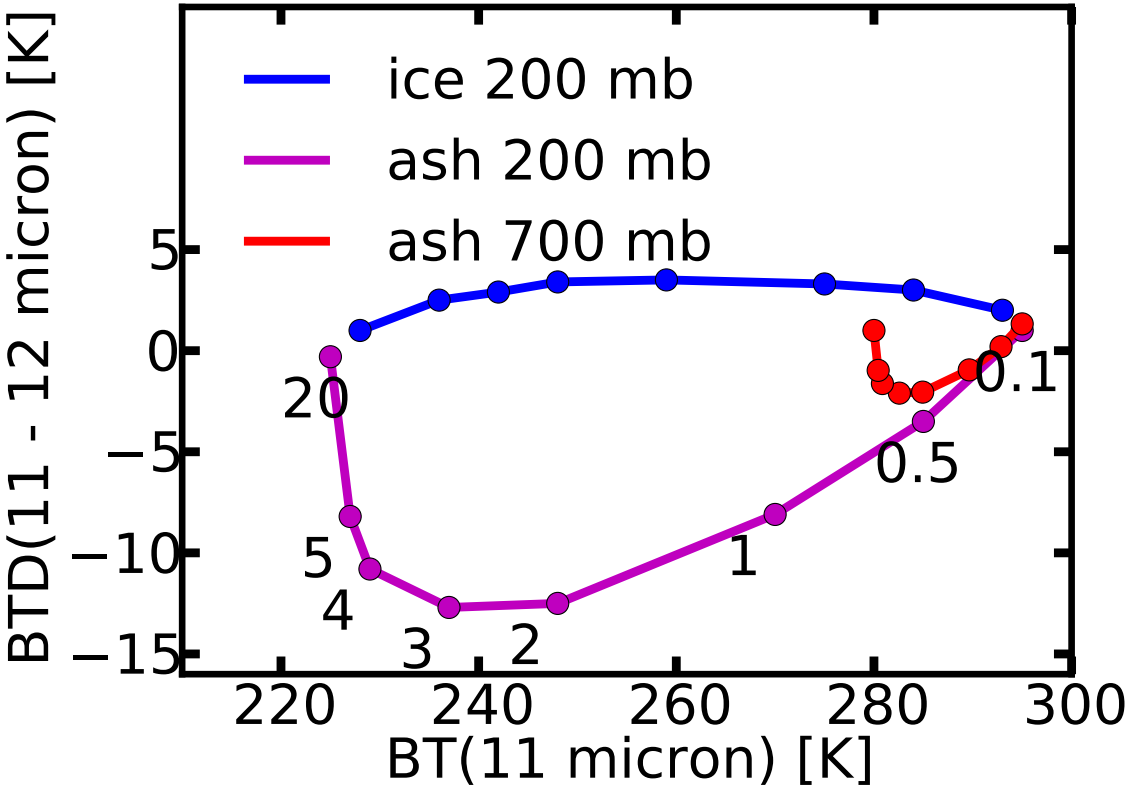


Figure 4 : $\theta_0 = 30^\circ, \theta = 10^\circ$, mid-latitude summer
$\tau_{0.65} = 0.1, 0.5, 1, 2, 3, 4, 5, 20$

Split Window Ash Detection R(3.75/0.65) > 1

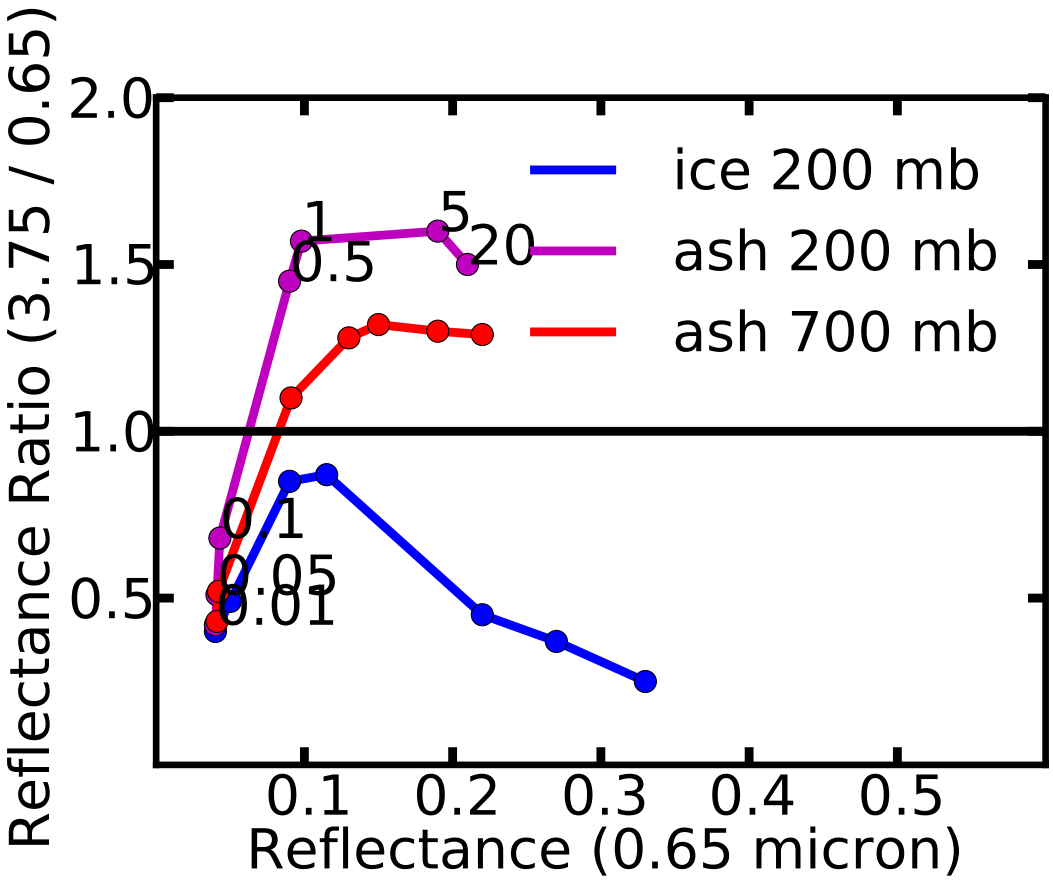


Figure 5 : $\theta_0 = 30^\circ, \theta = 10^\circ$, mid-latitude summer, $\tau_{0.65} = 0.01, 0.05, 0.1, 0.5, 1, 5, 20$

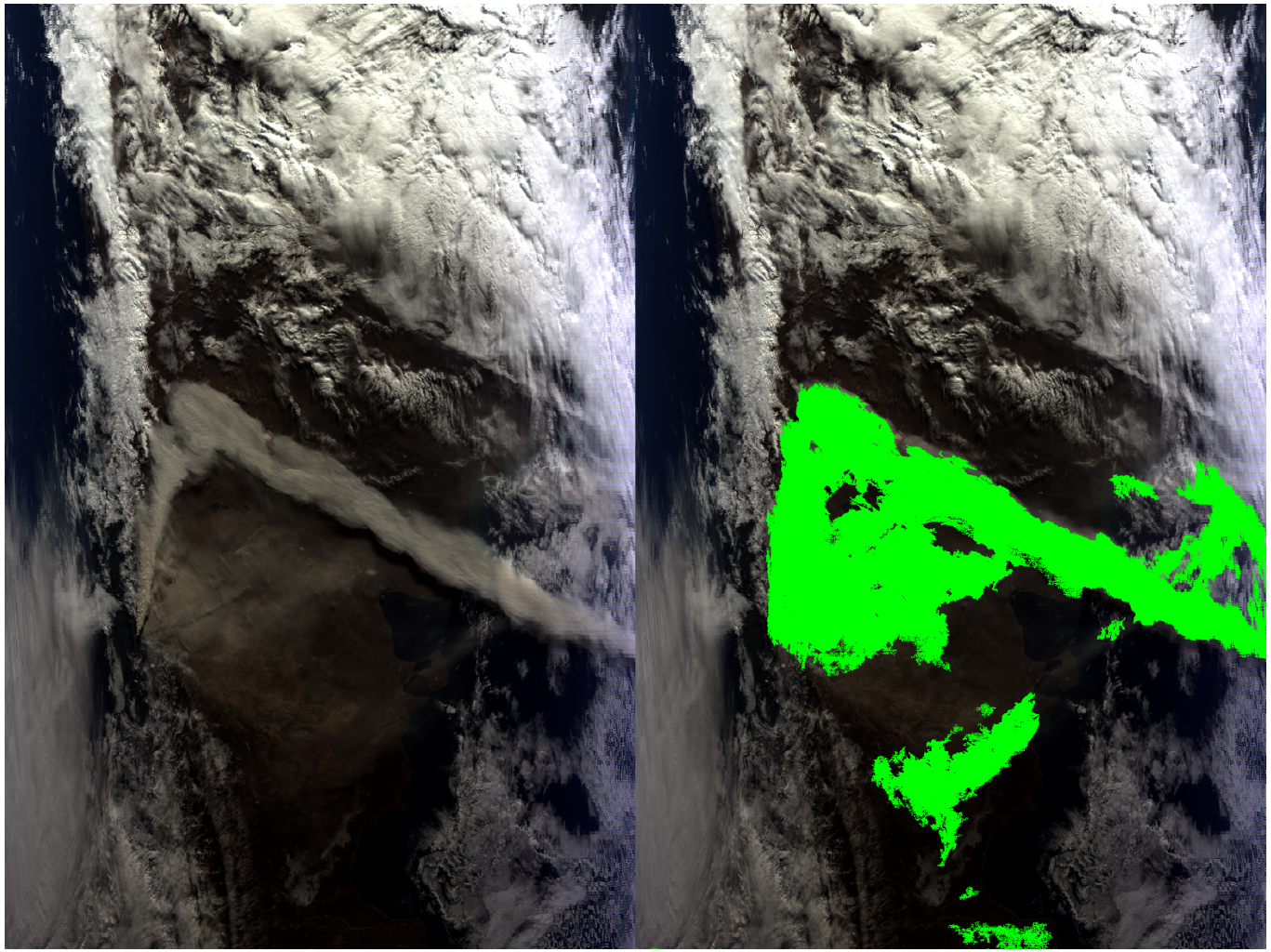


Figure 6 : Puyehue 2011 June 6, Terra MODIS 1 km true color and split window ash detection.

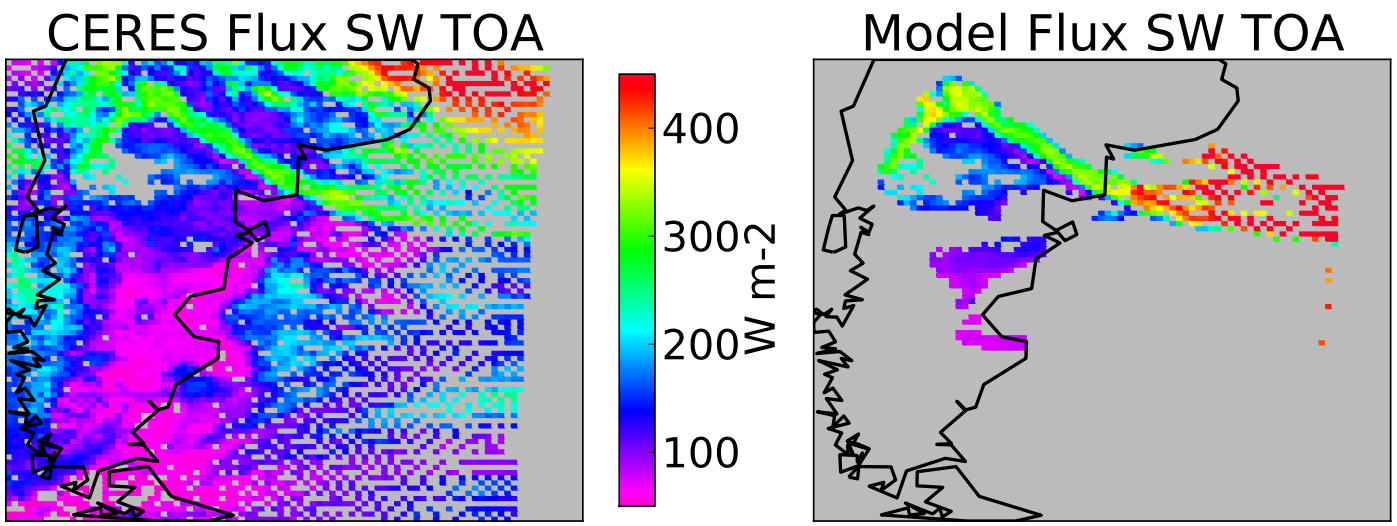
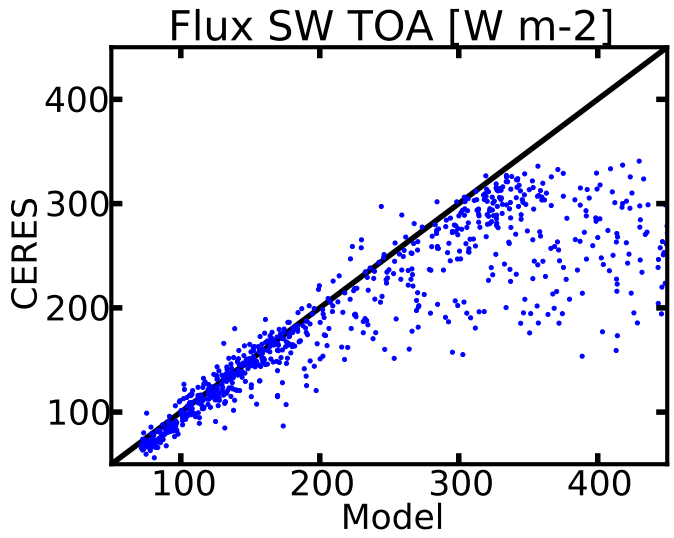


Figure 7 : 2011 June 6 Puyehue.



SSF SW TOA Flux

CERES mean 195 W m^{-2}
model mean 249 W m^{-2}
RMSE 77 W m^{-2}

$F < 350\ \mathrm{Wm}^{-2}$
CERES mean 172 W m^{-2}
model mean 189 W m^{-2}
RMSE 28 W m^{-2}

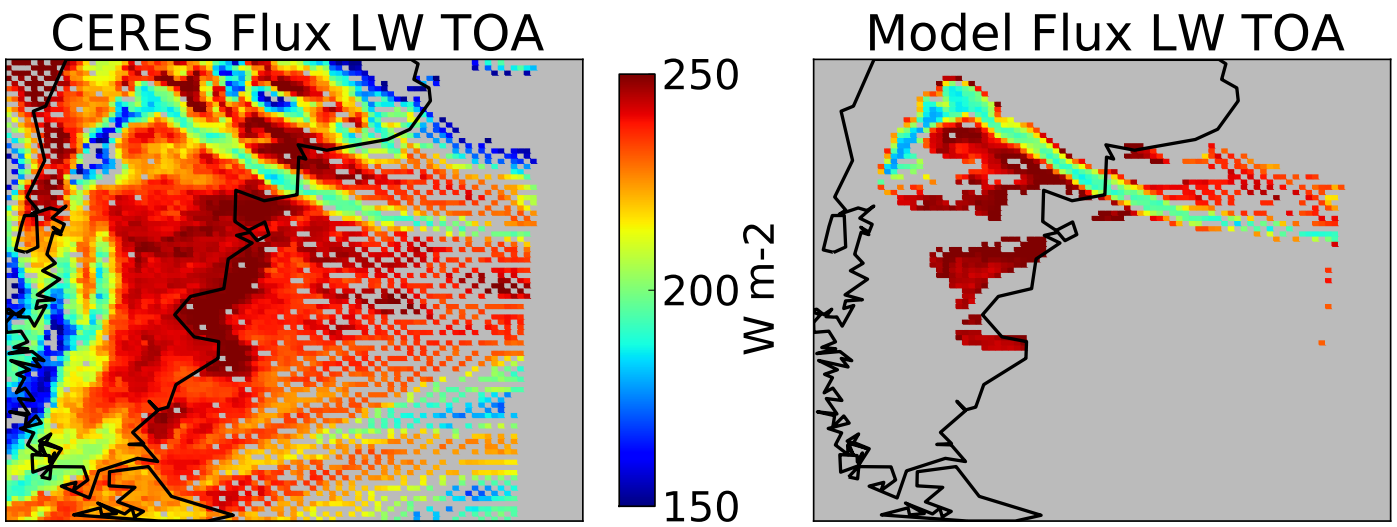
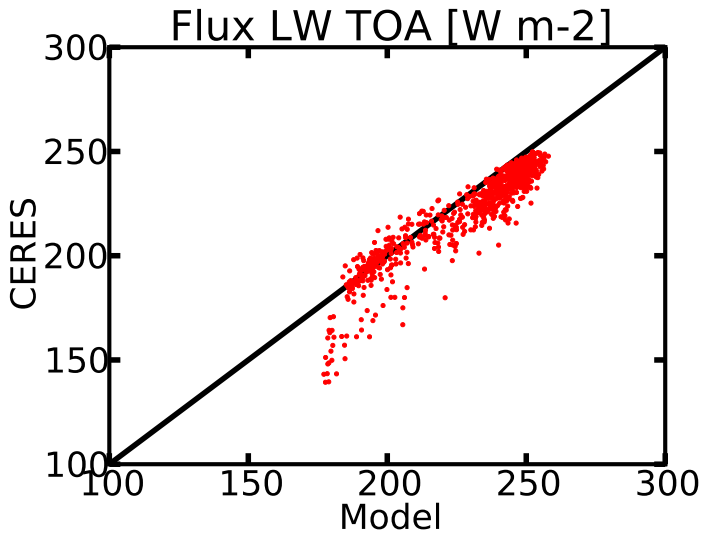


Figure 8 : 2011 June 6 Puyehue.



SSF LW TOA Flux

CERES mean 221 W m^{-2}
model mean 229 W m^{-2}
RMSE 10 W m^{-2}

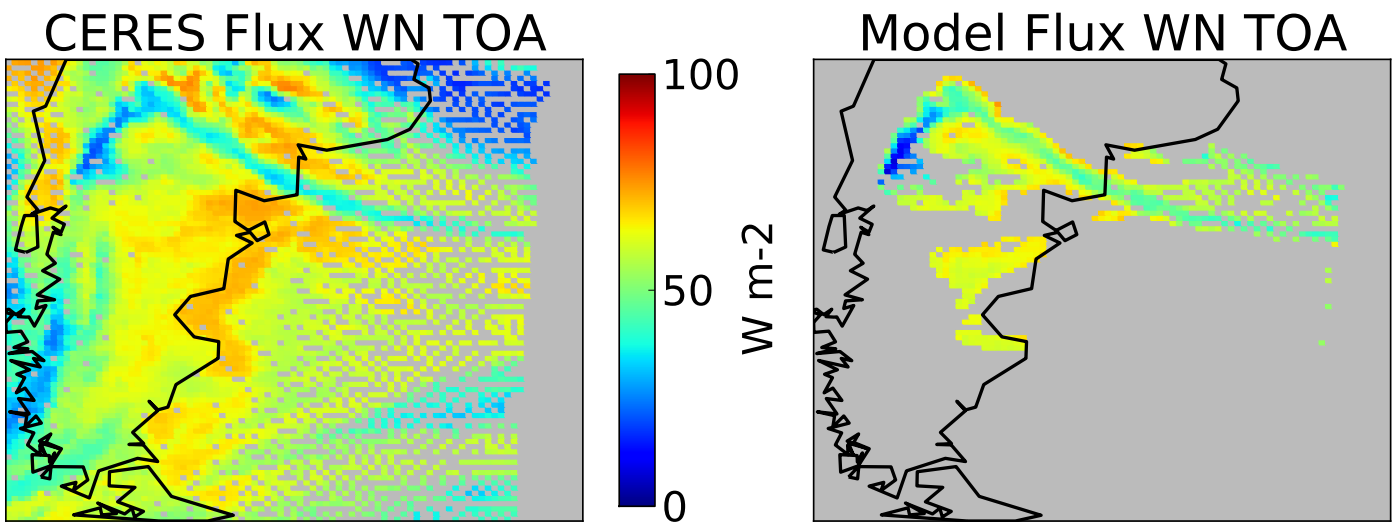
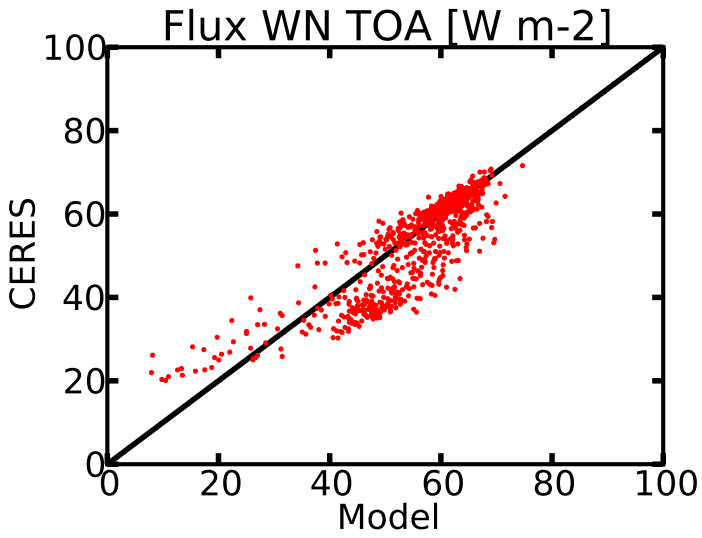


Figure 9 : 2011 June 6 Puyehue.



SSF WN TOA Flux

CERES mean 54 W m^{-2}
model mean 56 W m^{-2}
RMSE 7 W m^{-2}

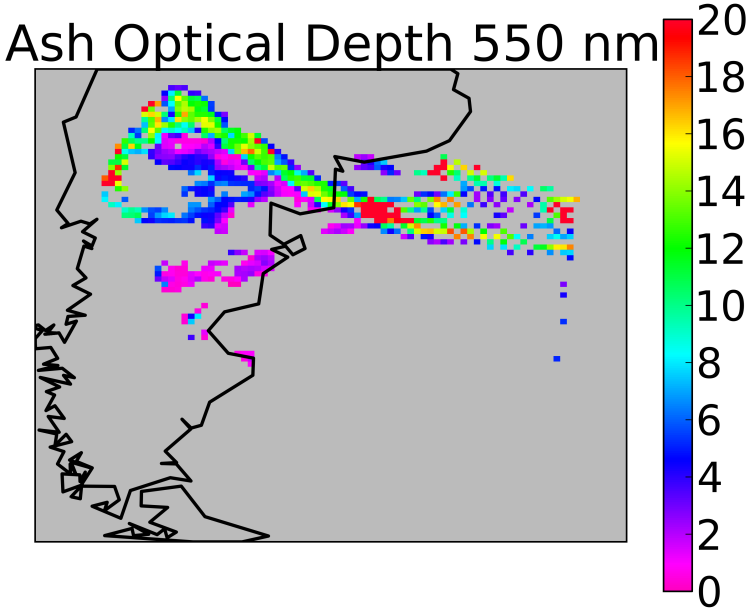


Figure 10 : Ash optical depth at 0.55 μm, 2011 June 6 Puyehue.

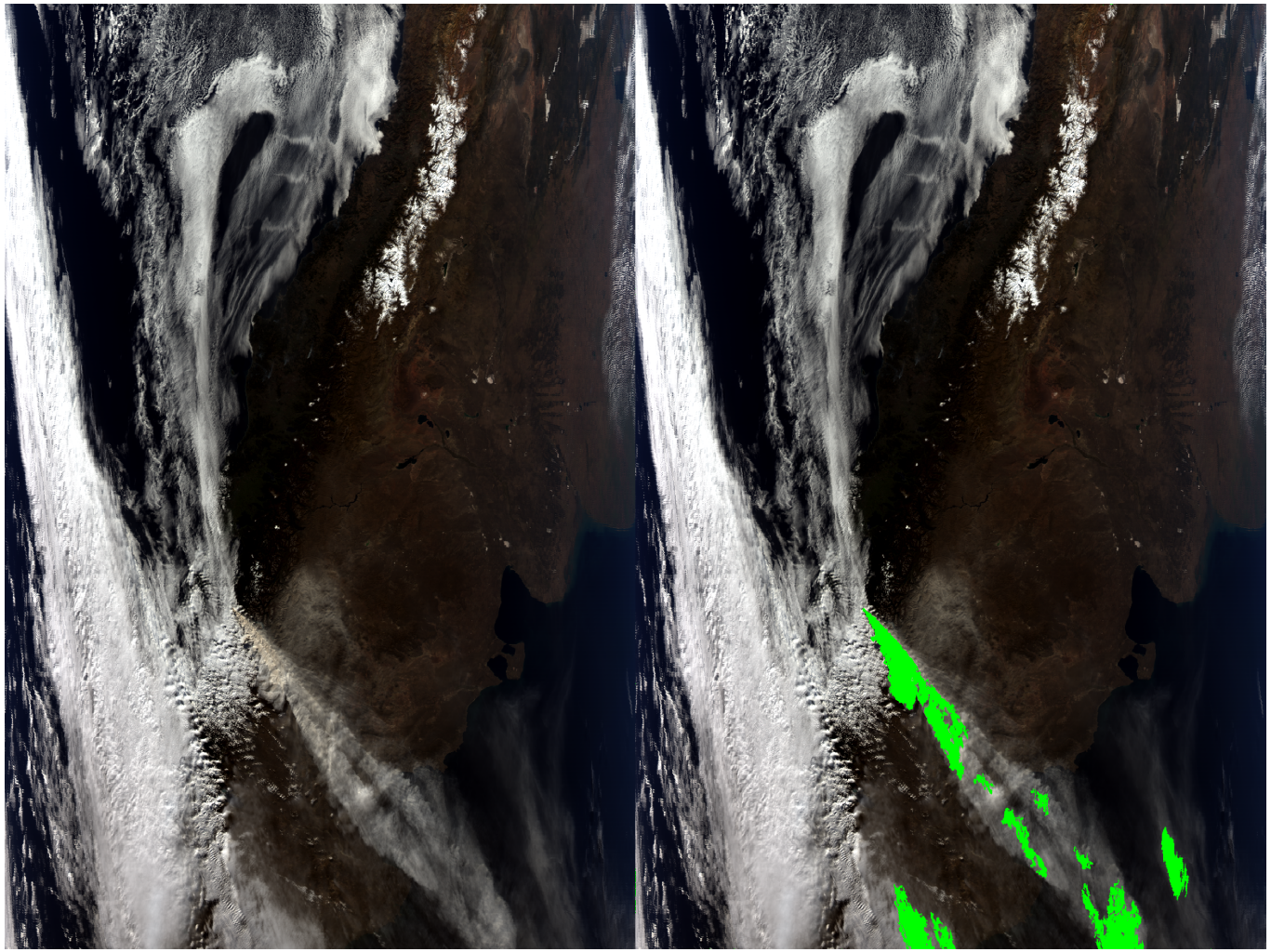


Figure 11 : Chaitén 2008 May 3, Aqua MODIS 1 km true color and split window ash detection.

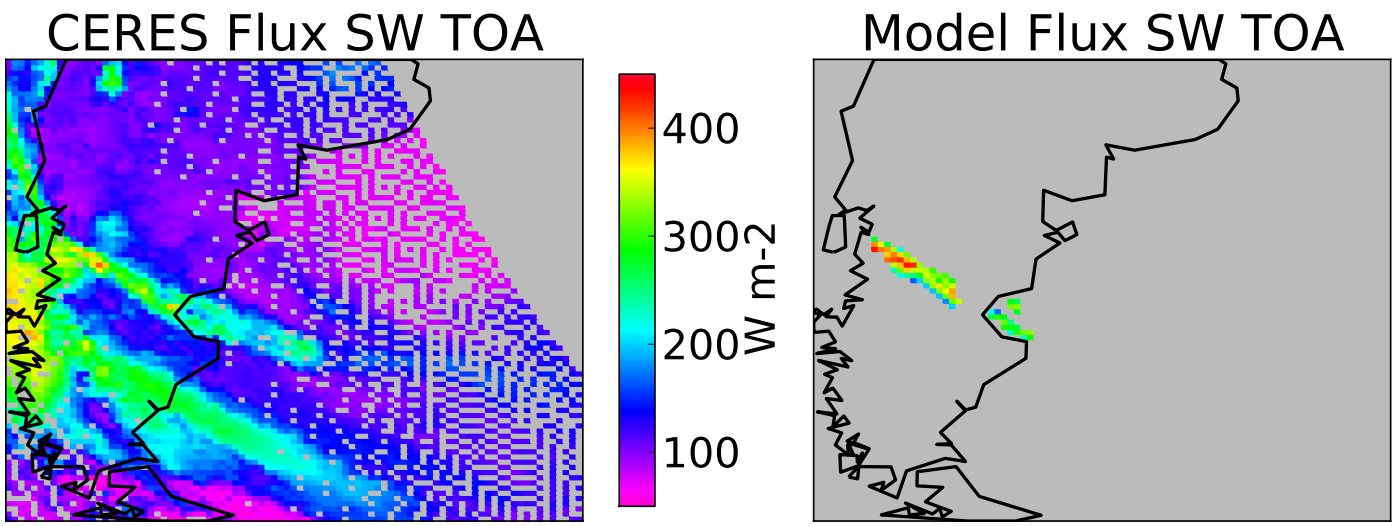
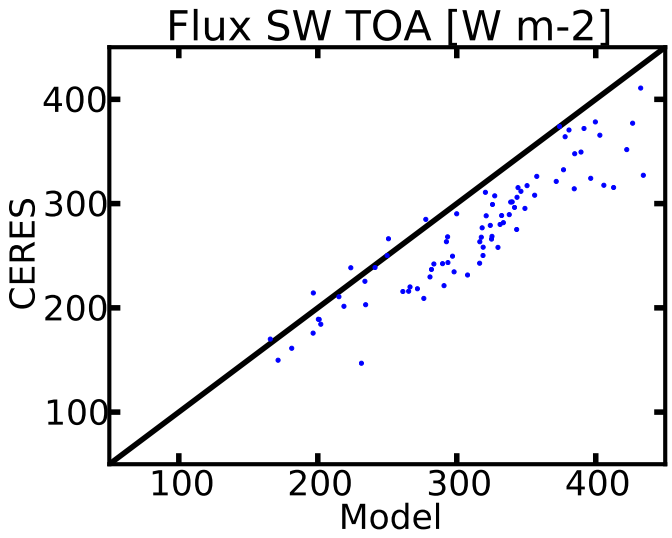


Figure 12 : 2008 May 3 Chaitén.



SSF SW TOA Flux

CERES mean 273 W m^{-2}
model mean 312 W m^{-2}
RMSE 26 W m^{-2}

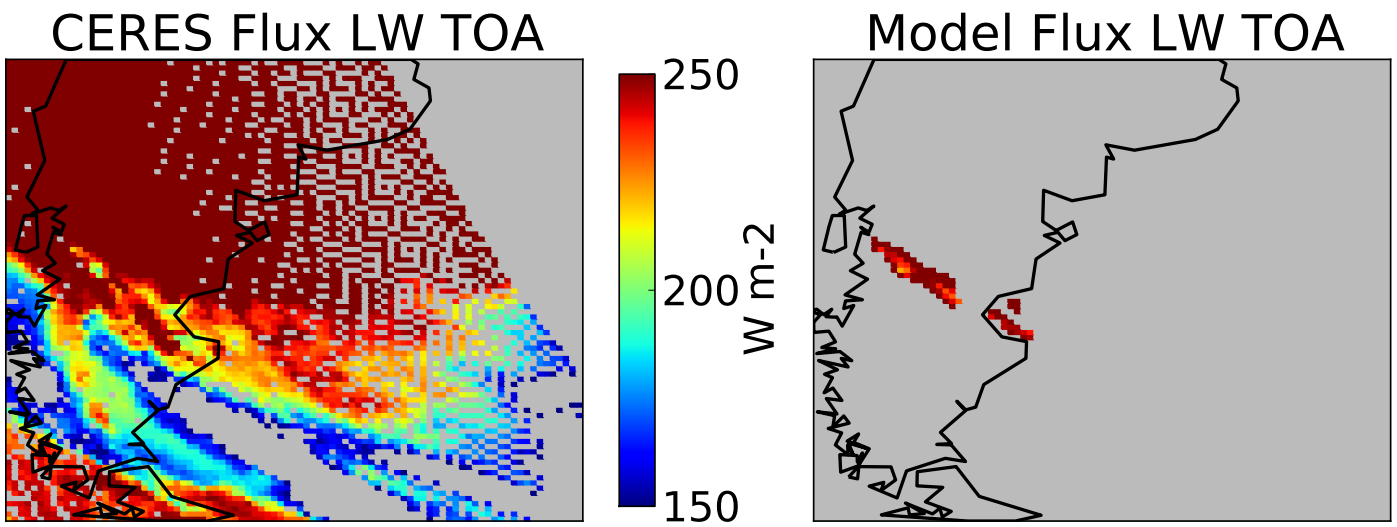
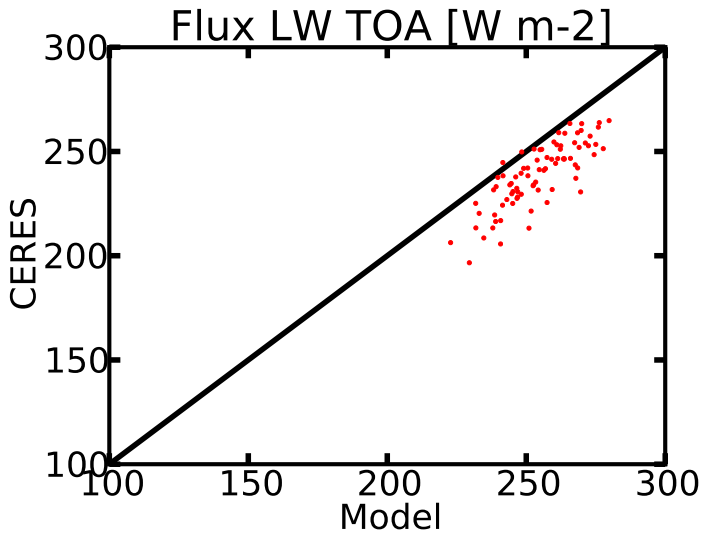


Figure 13 : 2008 May 3 Chaitén.



SSF LW TOA Flux

CERES mean 239 W m^{-2}
model mean 254 W m^{-2}
RMSE 9 W m^{-2}

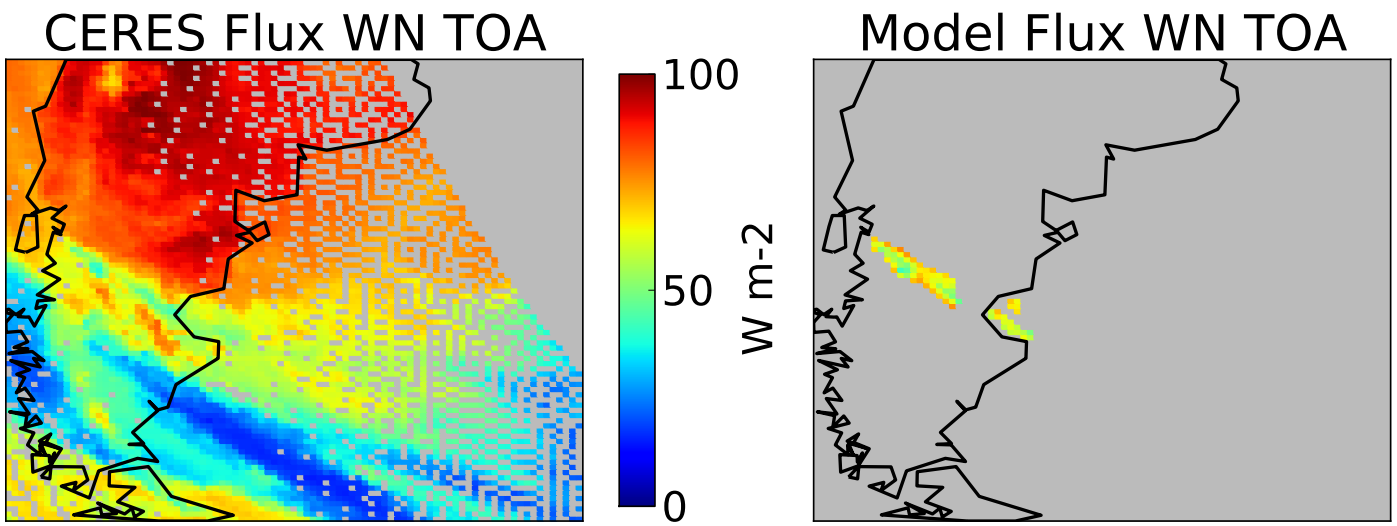
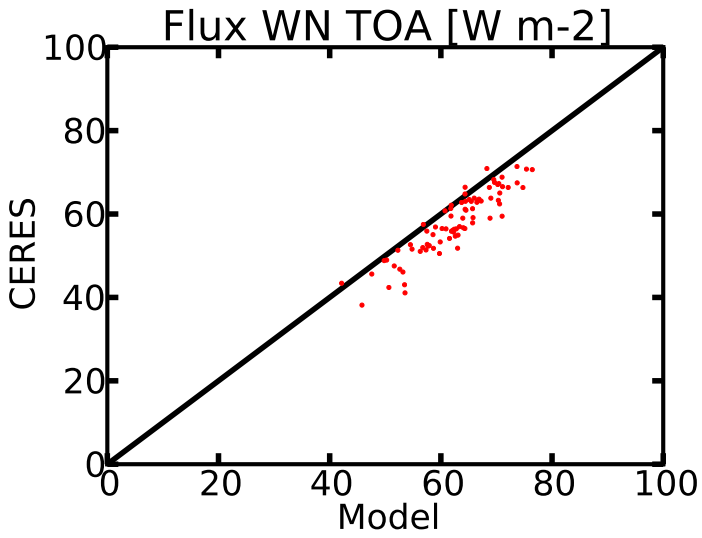


Figure 14 : 2008 May 3 Chaitén.



SSF WN TOA Flux

CERES mean 62 W m^{-2}
model mean 58 W m^{-2}
RMSE 3 W m^{-2}

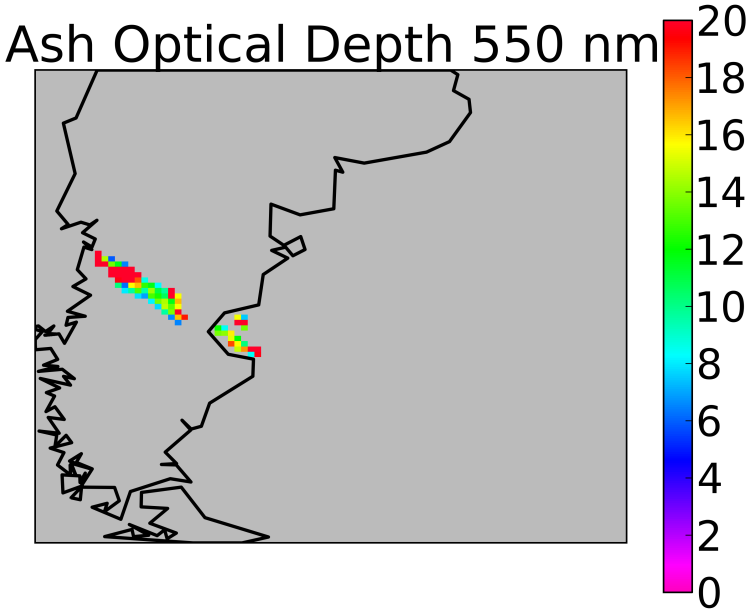


Figure 15 : Ash optical depth at 0.55 μm, 2008 May 3 Chaitén.

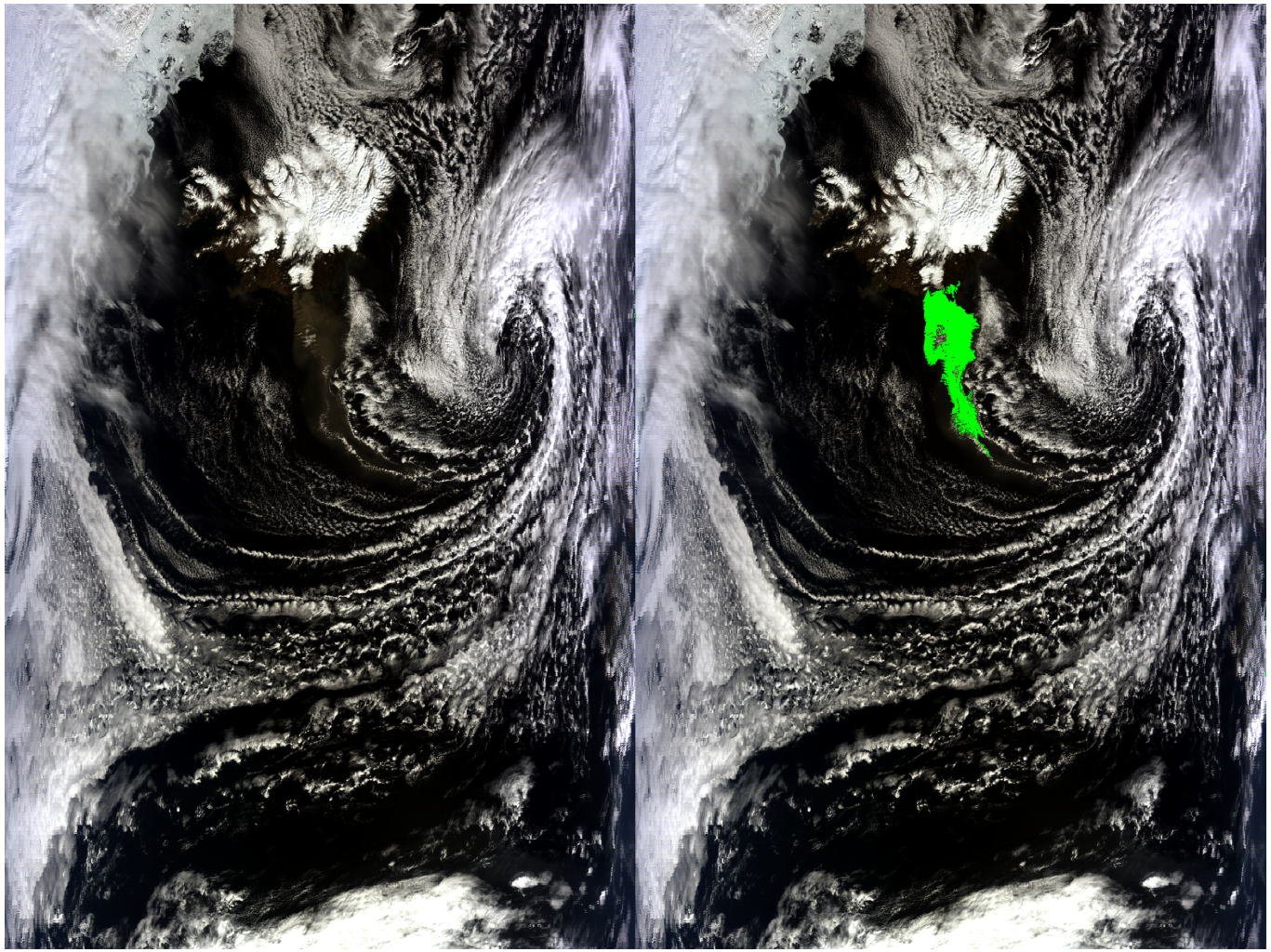


Figure 16 : Eyjafjallajökull 2010 April 19 Terra MODIS 1 km true color and split window ash detection. See, e.g., Christopher [1].

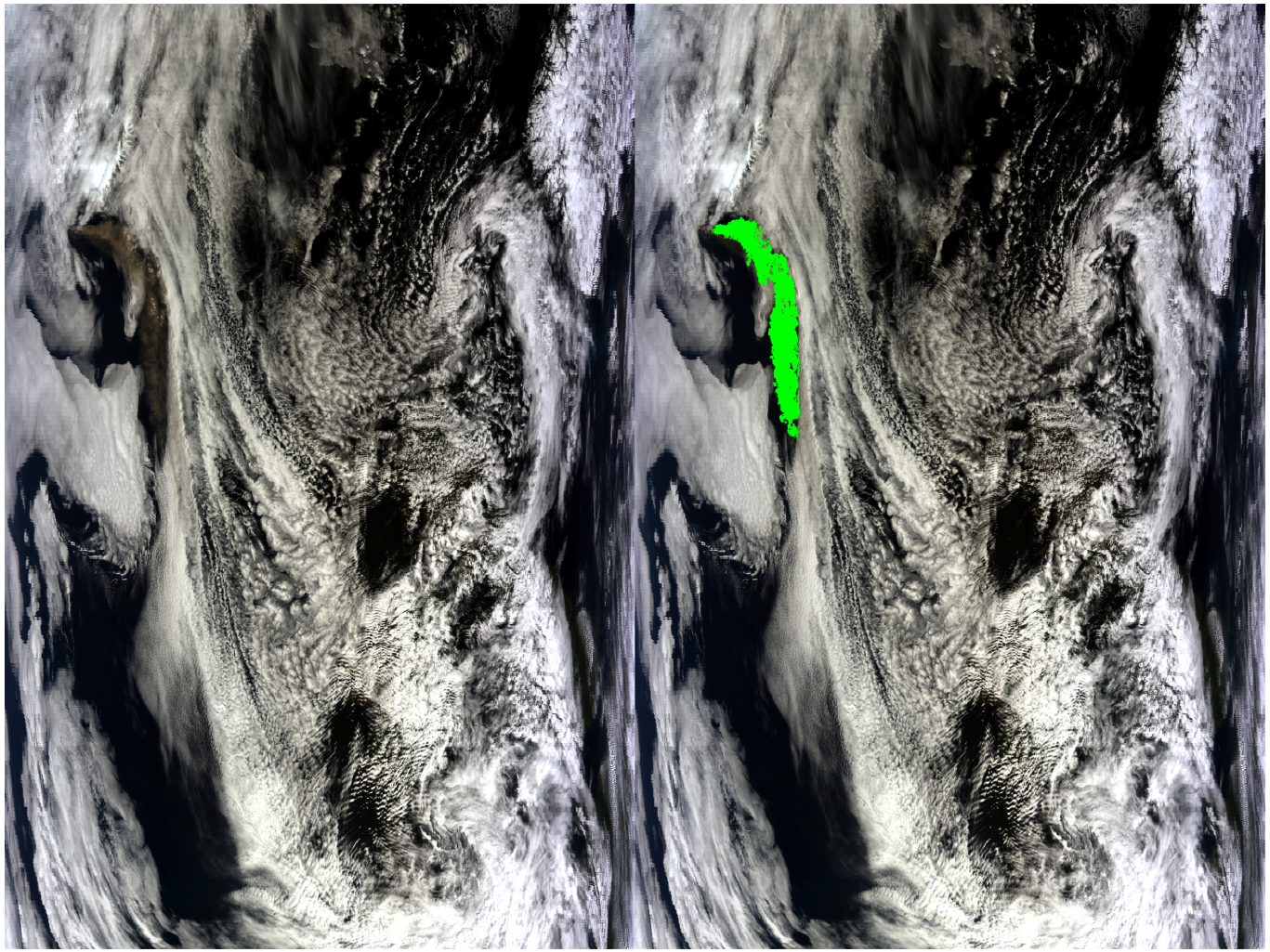


Figure 17 : Eyjafjallajökull 2010 May 6 Terra MODIS 1 km true color and split window ash detection.

Summary

1. Split window MODIS ash detection effective in most cases
2. Requires tuning threshold parameters by volcanic eruption
3. Can the algorithm be automated?
4. Radiative transfer model over ash plumes agrees well with CERES TOA fluxes, generally within random ADM error

Next Steps

1. Use $\mathrm{C^3M}$ plume height information
2. Evaluation of SARB MATCH aerosol assimilation
3. Find more volcanic events
4. Continue with wildfire events

[1] Sundar A. Christopher, Nan Feng, Aaron Naeger, Ben Johnson, and Franco Marenco.
Satellite remote sensing analysis of the 2010 Eyjafjallajökull volcanic ash cloud over the North Sea during 4-18 May 2010.
J. Geophys. Res., 117:D00U20, Mar 2012.
URL: http://dx.doi.org/10.1029/2011JD016850, doi:10.1029/2011JD016850.

[2] G. Gangale, A.J. Prata, and L. Clarisse.
The infrared spectral signature of volcanic ash determined from high-spectral resolution satellite measurements.
Remote Sensing of Environment, 114(2):414 – 425, 2010.
URL: http://www.sciencedirect.com/science/article/pii/S003442570900279X, doi:10.1016/j.rse.2009.09.007.

[3] Seiji Kato, Fred G. Rose, Sunny Sun-Mack, Walter F. Miller, Yan Chen, David A. Rutan, Graeme L. Stephens, Norman G. Loeb, Patrick Minnis, Bruce A. Wielicki, David M. Winker, Thomas P. Charlock, Paul W. Jr Stackhouse, Kuan-Man Xu, and William D. Collins.
Improvements of top-of-atmosphere and surface irradiance computations with CALIPSO-, CloudSat-, and MODIS-derived cloud and aerosol properties.
J. Geophys. Res., 116(D19):D19209, Oct 2011.
URL: http://dx.doi.org/10.1029/2011JD016050, doi:10.1029/2011JD016050.

[4] Norman G. Loeb, Seiji Kato, Konstantin Loukachine, and Natividad Manalo-Smith.
Angular distribution models for top-of-atmosphere radiative flux estimation from the clouds and the Earth's radiant energy system instrument on the Terra satellite. Part I: Methodology.
Journal of Atmospheric and Oceanic Technology, 22(4):338–351, Apr 2005.
URL: http://dx.doi.org/10.1175/JTECH1712.1, doi:10.1175/JTECH1712.1.

[5] Norman G. Loeb, Seiji Kato, Konstantin Loukachine, Natividad Manalo-Smith, and David R. Doelling.
Angular distribution models for top-of-atmosphere radiative flux estimation from the clouds and the Earth's radiant energy system instrument on the Terra satellite. Part II: Validation.
Journal of Atmospheric and Oceanic Technology, 24(4):564–584, Apr 2007.
URL: http://dx.doi.org/10.1175/JTECH1983.1, doi:10.1175/JTECH1983.1.

[6] Norman G. Loeb, Bruce A. Wielicki, David R. Doelling, G. Louis Smith, Dennis F. Keyes, Seiji Kato, Natividad Manalo-Smith, and Takmeng Wong.
Toward optimal closure of the Earth's top-of-atmosphere radiation budget.
Journal of Climate, 22(3):748–766, Feb 2009.
URL: http://dx.doi.org/10.1175/2008JCLI2637.1, doi:10.1175/2008JCLI2637.1.

[7] B. Mayer and A. Kylling.
Technical note: The libRadtran software package for radiative transfer calculations - description and examples of use.
Atmospheric Chemistry and Physics, 5(7):1855–1877, 2005.
URL: http://www.atmos-chem-phys.net/5/1855/2005/, doi:10.5194/acp-5-1855-2005.

[8] O. Muñoz, H. Volten, J. W. Hovenier, B. Veihelmann, W. J. van der Zande, L. B. F. M. Waters, and W. I. Rose.
Scattering matrices of volcanic ash particles of Mount St. Helens, Redoubt, and Mount Spurr volcanoes.
J. Geophys. Res., 109(D16):D16201, Aug 2004.
URL: http://dx.doi.org/10.1029/2004JD004684, doi:10.1029/2004JD004684.

[9] Michael J. Pavolonis, Wayne F. Feltz, Andrew K. Heidinger, and Gregory M. Gallina.
A daytime complement to the reverse absorption technique for improved automated detection of volcanic ash.
Journal of Atmospheric and Oceanic Technology, 23(11):1422–1444, Nov 2006.
URL: http://dx.doi.org/10.1175/JTECH1926.1, doi:10.1175/JTECH1926.1.

[10] L. A. Remer, Y. J. Kaufman, D. Tanré, S. Mattoo, D. A. Chu, J. V. Martins, R.-R. Li, C. Ichoku, R. C. Levy, R. G. Kleidman, T. F. Eck, E. Vermote, and B. N. Holben.
The MODIS aerosol algorithm, products, and validation.
Journal of the Atmospheric Sciences, 62(4):947–973, Apr 2005.
URL: http://dx.doi.org/10.1175/JAS3385.1, doi:10.1175/JAS3385.1.

[11] A. Stohl, A. J. Prata, S. Eckhardt, L. Clarisse, A. Durant, S. Henne, N. I. Kristiansen, A. Minikin, U. Schumann, P. Seibert, K. Stebel, H. E. Thomas, T. Thorsteinsson, K. Tørseth, and B. Weinzierl.
Determination of time- and height-resolved volcanic ash emissions for quantitative ash dispersion modeling: the 2010 Eyjafjallajökull eruption.
Atmospheric Chemistry and Physics Discussions, 11(2):5541–5588, 2011.
URL: http://www.atmos-chem-phys-discuss.net/11/5541/2011/, doi:10.5194/acpd-11-5541-2011.

[12] I.M Watson, V.J Realmuto, W.I Rose, A.J Prata, G.J.S Bluth, Y Gu, C.E Bader, and T Yu.
Thermal infrared remote sensing of volcanic emissions using the moderate resolution imaging spectroradiometer.
Journal of Volcanology and Geothermal Research, 135(12):75 – 89, 2004.
Volcanic Observations from Space: New Results from the EOS Satellite Instruments.
URL: http://www.sciencedirect.com/science/article/pii/S0377027304000307, doi:10.1016/j.jvolgeores.2003.12.017.

[13] Tianxu Yu, William I. Rose, and A. J. Prata.
Atmospheric correction for satellite-based volcanic ash mapping and retrievals using split window IR data from GOES and AVHRR.
J. Geophys. Res., 107(D16):4311, Aug 2002.
URL: http://dx.doi.org/10.1029/2001JD000706, doi:10.1029/2001JD000706.