Centrum Badań Kosmicznych
Polskiej Akademii Nauk

COST
EUROPEAN COOPERATION
IN SCIENCE AND TECHNOLOGY

Polarisation as a tool to study the Solar System and beyond

Action MP1104

COST MP1104 Workshop
Warsaw 7-9 May 2012

Polarisation Technique in SMOS Earth Observations

(Planck, Stokes and SMOS)

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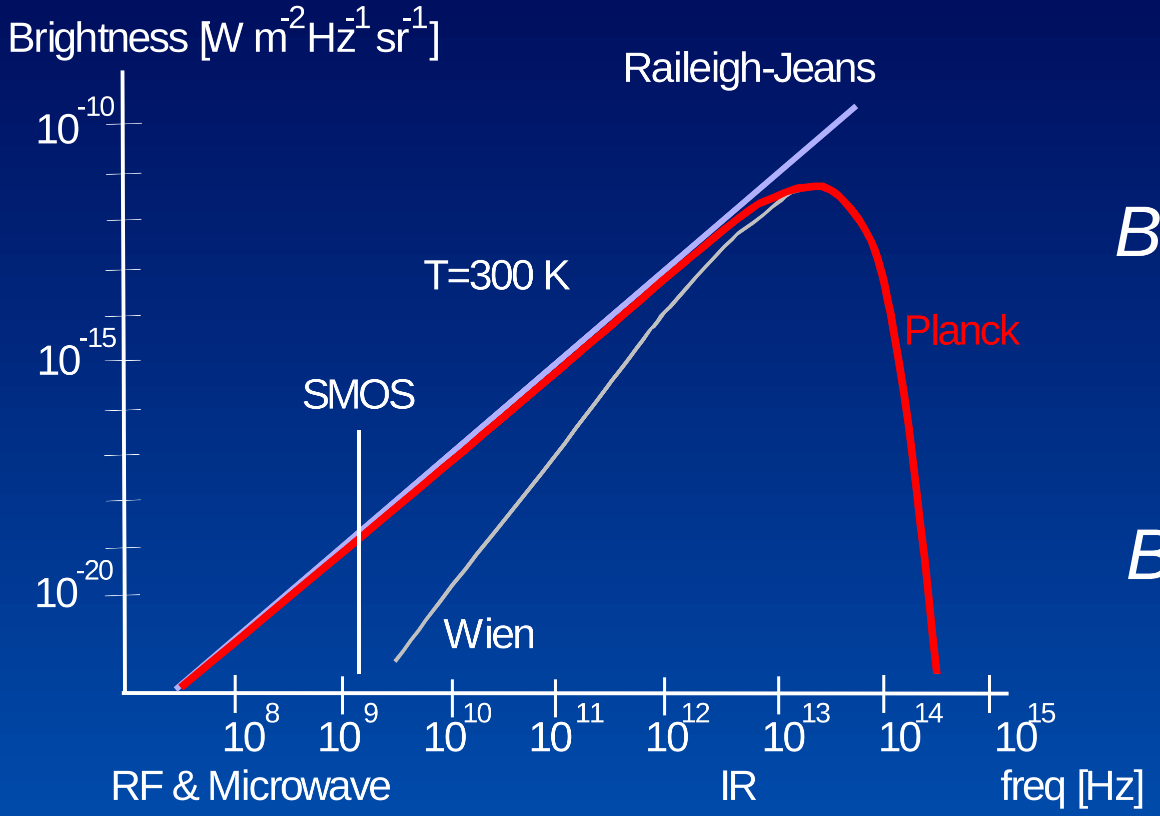
Plan of presentation

1 - Brightness Temperature
2 - Radiometric Sensitivity
3 - Reference Planes while observing from orbit
4 - Fresnel effects of horizontal media layers
5 - Real observational data in L1C level
6 - Real observational data in L2 and L3 levels
7 - RFI in Stokes elements
8 - Conclusion on the spinorial property of the method

Planck Law



Raileigh_Jeans

$$B(f,T) = \frac{2kT f^2}{c^2} \quad \frac{2kT}{\lambda^2}$$

Planck

$$B(f,T) = \frac{2h f^3}{c^2} \frac{1}{\exp\left(\frac{h f}{kT}\right) - 1}$$

h - Planck const.
k - Boltzmann const.

Black body absorbs radiaton perfectly but
Gray body absorbs and reflects/emitts radiation

Ignasi Corbella, Interferometric Aperture Synthesis for Earth Observations, ESA ESTEC, 2008 and "The Visibility Function in Interferometric Aperture Synthesis Radiometry", IEEE TGRS VOL. 42, NO. 8, AUGUST 2004, pp. 1667-1682

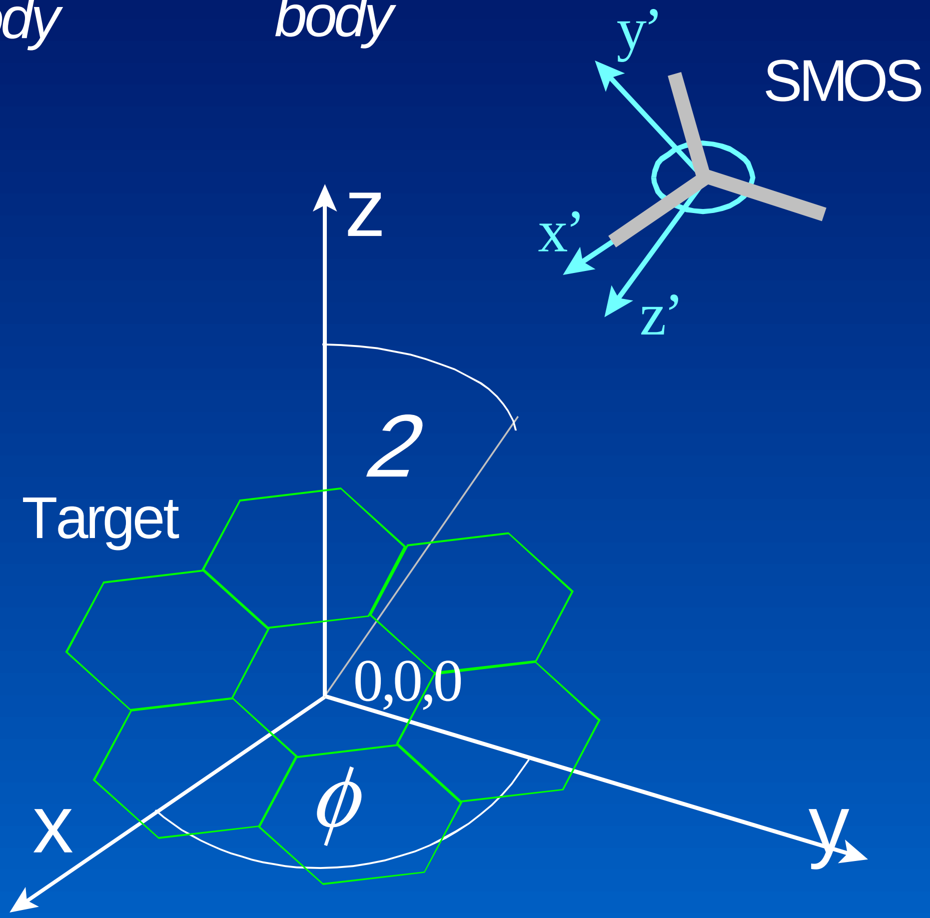
Observing non-black body

$$B_{nb}(2,\phi) = B_{bb}(1-\Gamma(2,\phi)) = B_{bb}\, e(2,\phi)$$

non black body — black body

emissivity

$$0 \leqslant e(2,\phi) \leqslant 1$$

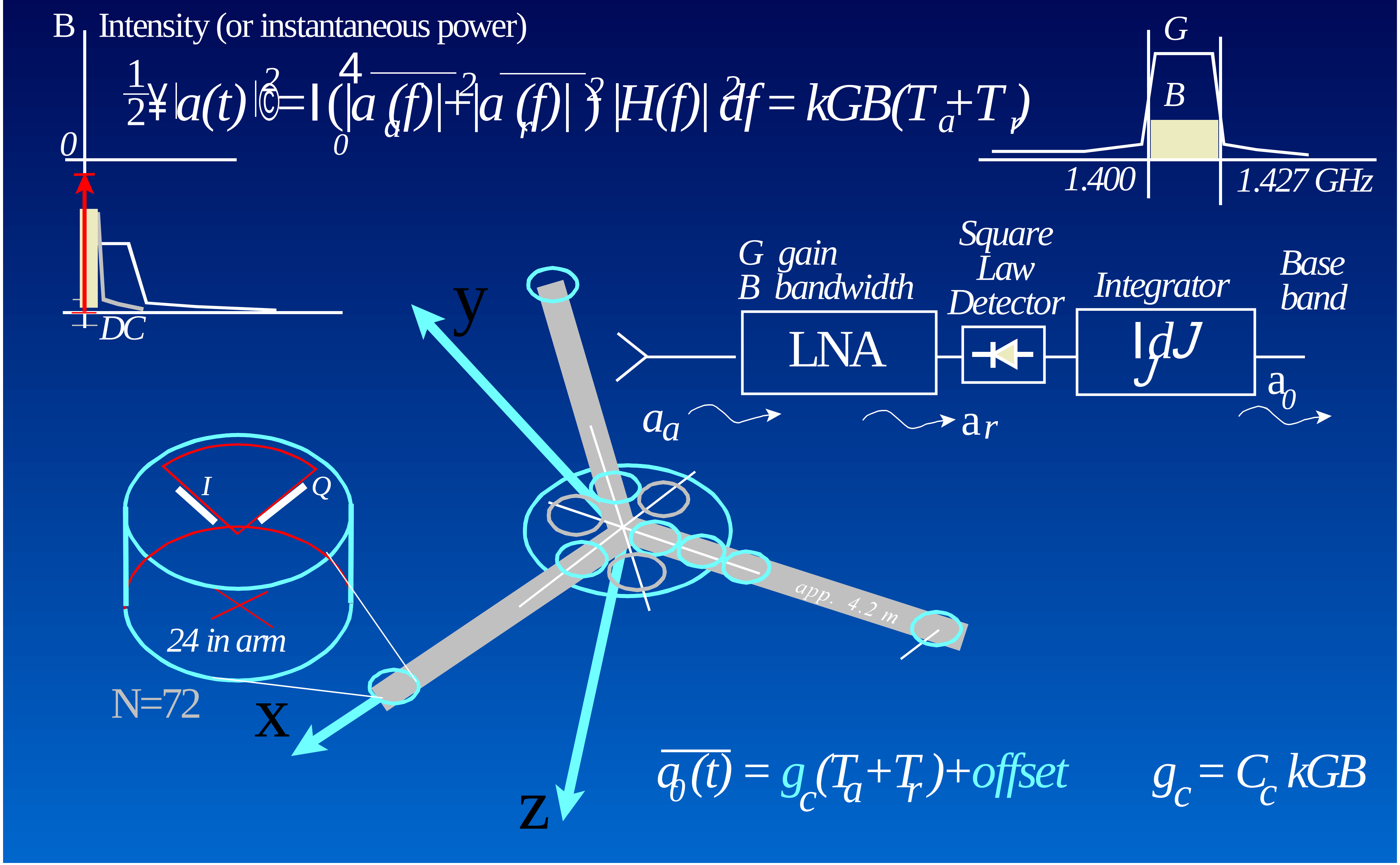


$$T_B(2,\phi) = e(2,\phi)T$$

$$B_{nb}(2,\phi) = \frac{2k}{\lambda^2}\, T_B(2,\phi)$$

$$S(2,\phi) = \frac{2kT_B(2,\phi)}{\lambda^2}\,\Delta\Omega$$

Basic radiometric operations



Radiometric Sensitivity

$$)T = \frac{T_a + T_r}{\sqrt{BJ}}$$

$$F = \overline{p} = kGB\,(T_{sys} + T_{measured})$$

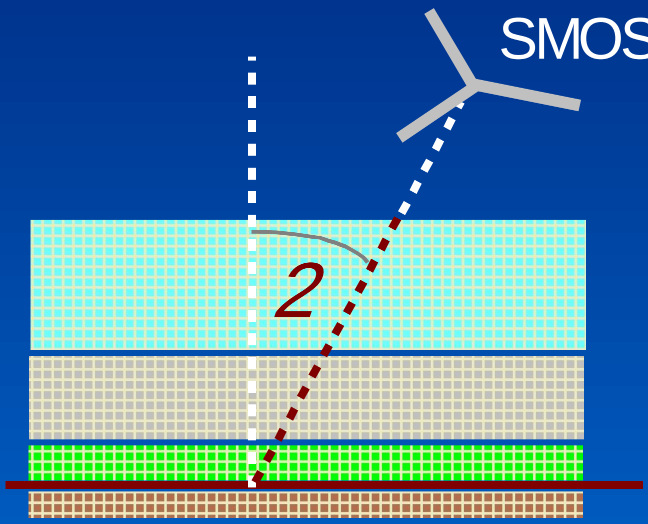
k - Boltzmann const.
G - gain
B - bandwidth

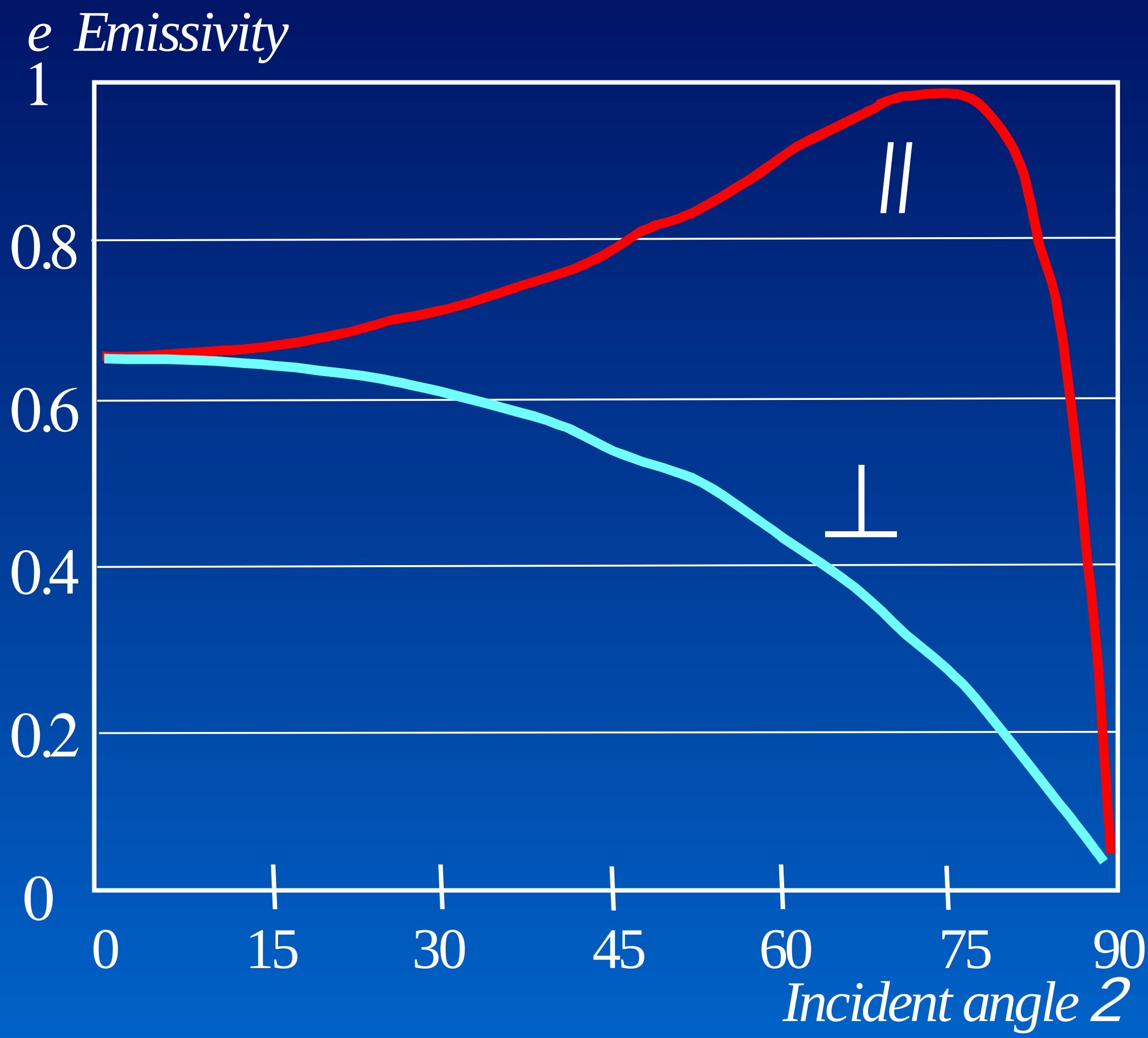
$$v_0(t) - offset = C_c\, l_J\, p(t)dt \quad Y \quad F_{out} = \frac{C_c\,\overline{p(t)}}{\sqrt{BJ}} = \frac{gT_{sys}}{\sqrt{BJ}}$$

Fresnel transfer of emission and reflection

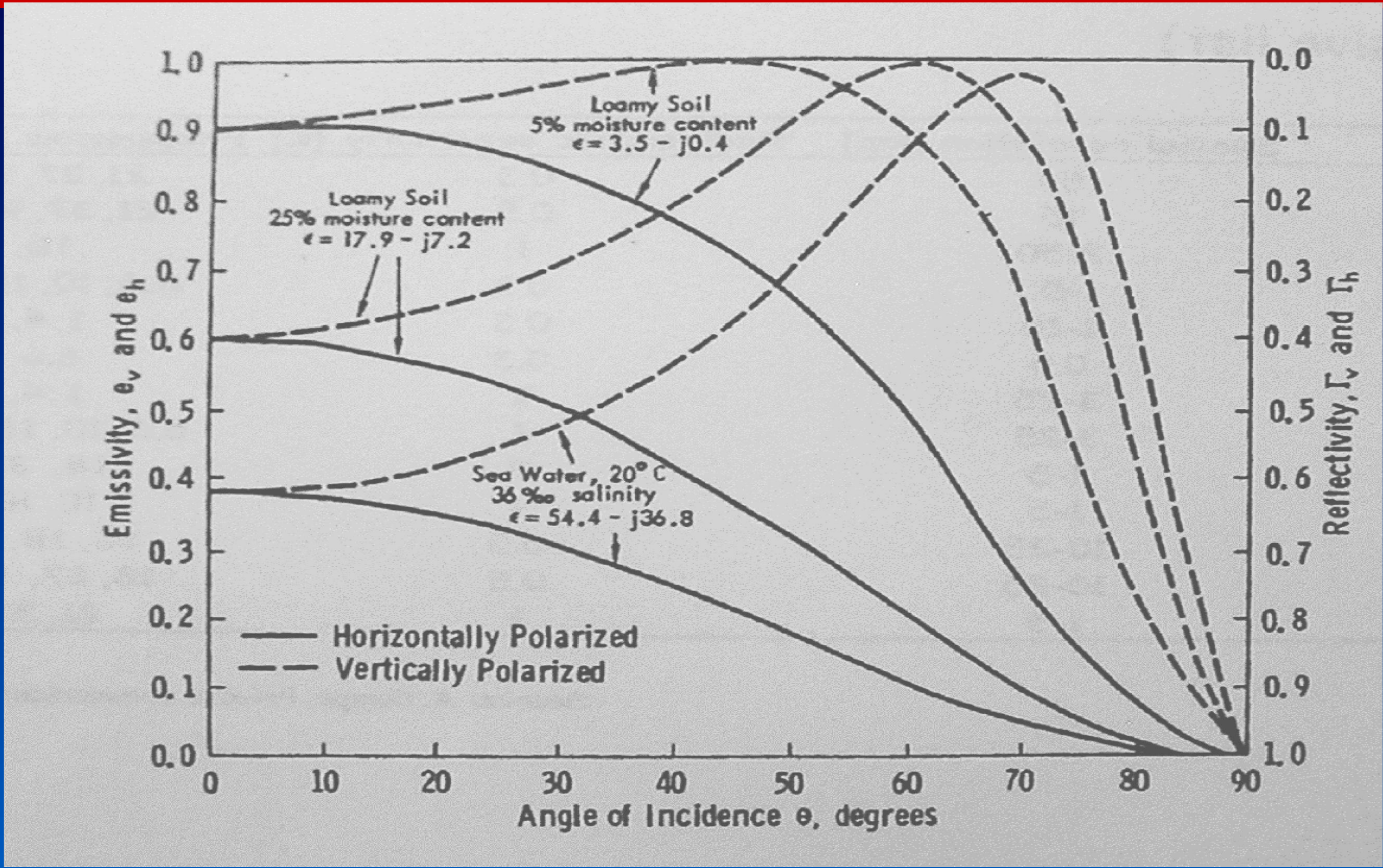
$0 \leqslant e(2) \leqslant 1$

$e(2) = 1 - \Gamma(2)$



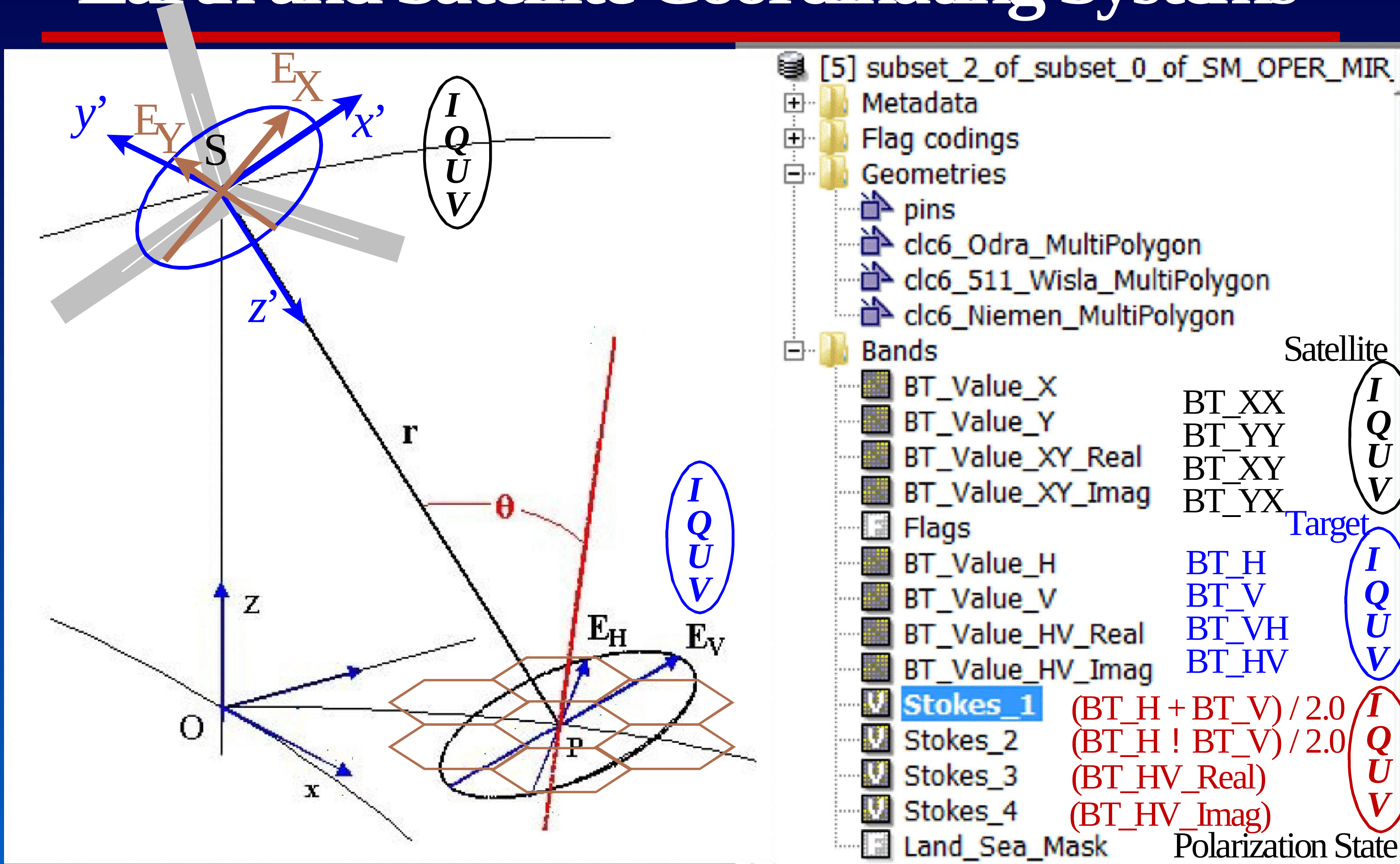


Soil Ground Target



F. Ulaby, R. Moore, A. Fung, "Microwave Remote Sensing, Active and Passive M-ve RS Fundamentals" ,Addison-Weseley 1981

Earth and Satellite Coordinating Systems



Algorithm Theoretical Basis Document (ATBD) for the SMOS Level 2 Soil Moisture Processor Development Continuation Project Project", ESA No.: SO-TN- ARR-L2PP-0037 Issue: 3.4 ATBD_v3_4_20110124.pdf

Four Measurements

Intensity and state is represented by four measured values in power terms

$$\overline{E}(\hat{k}) = \langle \bar{e} \otimes \bar{e}^* \rangle = \begin{bmatrix} \langle |e_v|^2 \rangle \\ \langle e_v e_h^* \rangle \\ \langle e_h e_v^* \rangle \\ \langle |e_h|^2 \rangle \end{bmatrix}$$

I	I
Q	U
U	V
V	Q

The intensity E and polarization state of the wave measured in the direction $\hat{k}$ can be described by its coherency vector where the operator $\otimes$ indicates an outer product, and brackets $\langle \cdot \rangle$ denote an ensemble average of the argument. Because the electric field amplitude random processes are stationary and ergodic, there is no need to carry the time argument t.

(Piepmeier J., Stokes_Antenna_Temperatures_101109TGRS2007909597)

Degree of Polarisation

Note: *The author finds that the following thought experiment helps him to understand the significance of the Stokes parameters. The reader is invited to try it, too: if you get lost, blame the author and press on. J.W. Hovenier clarified an essential didactic point.*

Let us consider the normalized (i.e. $I = 1$) Stokes vector $1, q, u, v$, with degree of polarization $p = \sqrt{q^2 + u^2 + v^2}$. We can look on this as the sum of a 100% elliptically polarized part and a remainder, which is unpolarized:

$$\begin{pmatrix} 1 \\ q \\ u \\ v \end{pmatrix} = \begin{pmatrix} p \\ q \\ u \\ v \end{pmatrix} + \begin{pmatrix} 1 - p \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

For the polarized part, the parameters of the ellipse are: $\tan 2\chi = u/q$ and $\tan 2\beta = v/\sqrt{q^2 + u^2}$.

Jaap Tinbergen “Astronomical Polarimetry”, Cambridge University Press, 1996-2006, 158 pp., ISBN 0 521 475317

Decomposition on incoherent components

We may also split the vector into a 100% circularly polarized part, a 100% linearly polarized part and an unpolarized remainder:

$$\begin{pmatrix} 1 \\ q \\ u \\ v \end{pmatrix} = \begin{pmatrix} \sqrt{v^2} \\ 0 \\ 0 \\ v \end{pmatrix} + \begin{pmatrix} \sqrt{q^2+u^2} \\ q \\ u \\ 0 \end{pmatrix} + \begin{pmatrix} 1-\sqrt{v^2}-\sqrt{q^2+u^2} \\ 0 \\ 0 \\ 0 \end{pmatrix}$$

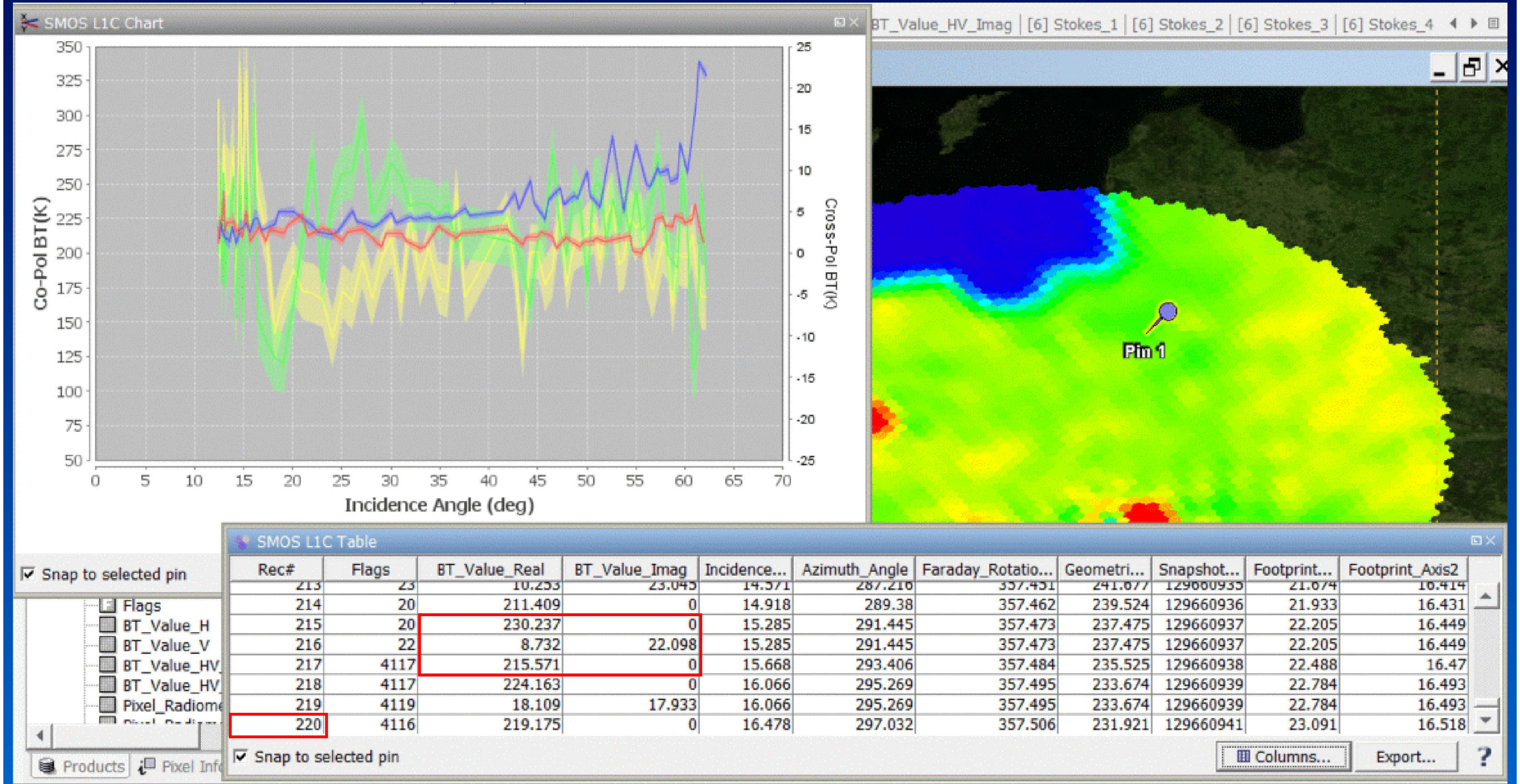
In both these Stokes vector equations, the components of the radiation are supposed *incoherent* with each other, or Stokes vector addition would not apply. The first representation is always possible, since $p \leq 1$ and the unpolarized part at worst reduces to zero. In the second representation, however, the intensity of the unpolarized part can become negative (a physical impossibility) if

$$\sqrt{v^2} + \sqrt{q^2+u^2} > 1$$

Jaap Tinbergen "Astronomical Polarimetry", Cambridge University Press, 1996-2006, 158 pp., ISBN 0 521 475317

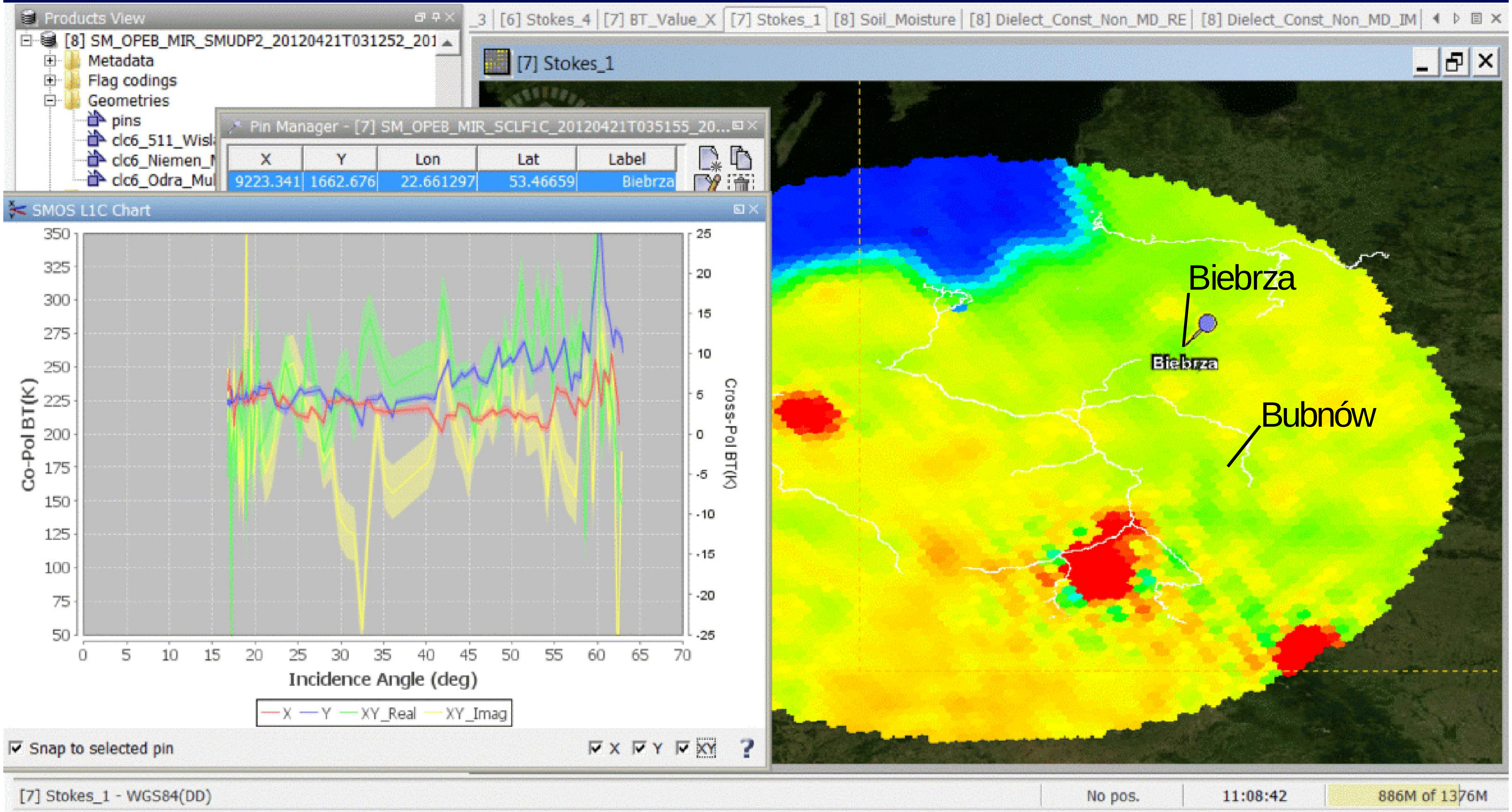
BT Observations in real data L1C

SM_OPEB_MIR_SCLF1C_20120421T035155_20120421T035524_505_118_1



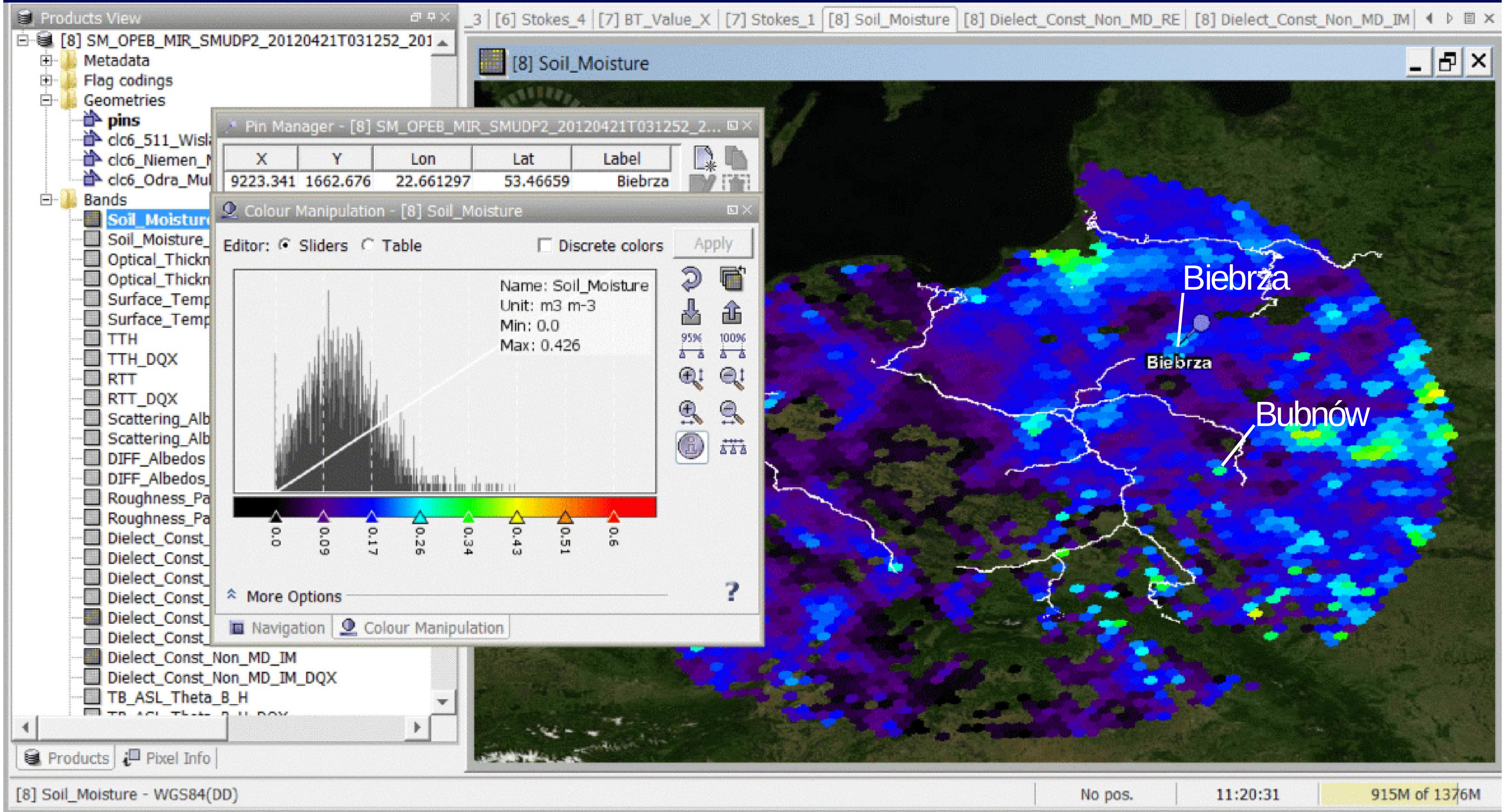
Rec#	Flags	BT_Value_Real	BT_Value_Imag	Incidence...	Azimuth_Angle	Faraday_Rotatio...	Geometri...	Snapshot...	Footprint...	Footprint_Axis2
213	23	10.253	23.045	14.571	287.216	357.451	241.677	129660935	21.674	16.414
214	20	211.409	0	14.918	289.38	357.462	239.524	129660936	21.933	16.431
215	20	230.237	0	15.285	291.445	357.473	237.475	129660937	22.205	16.449
216	22	8.732	22.098	15.285	291.445	357.473	237.475	129660937	22.205	16.449
217	4117	215.571	0	15.668	293.406	357.484	235.525	129660938	22.488	16.47
218	4117	224.163	0	16.066	295.269	357.495	233.674	129660939	22.784	16.493
219	4119	18.109	17.933	16.066	295.269	357.495	233.674	129660939	22.784	16.493
220	4116	219.175	0	16.478	297.032	357.506	231.921	129660941	23.091	16.518

BT Observations in real data L1C



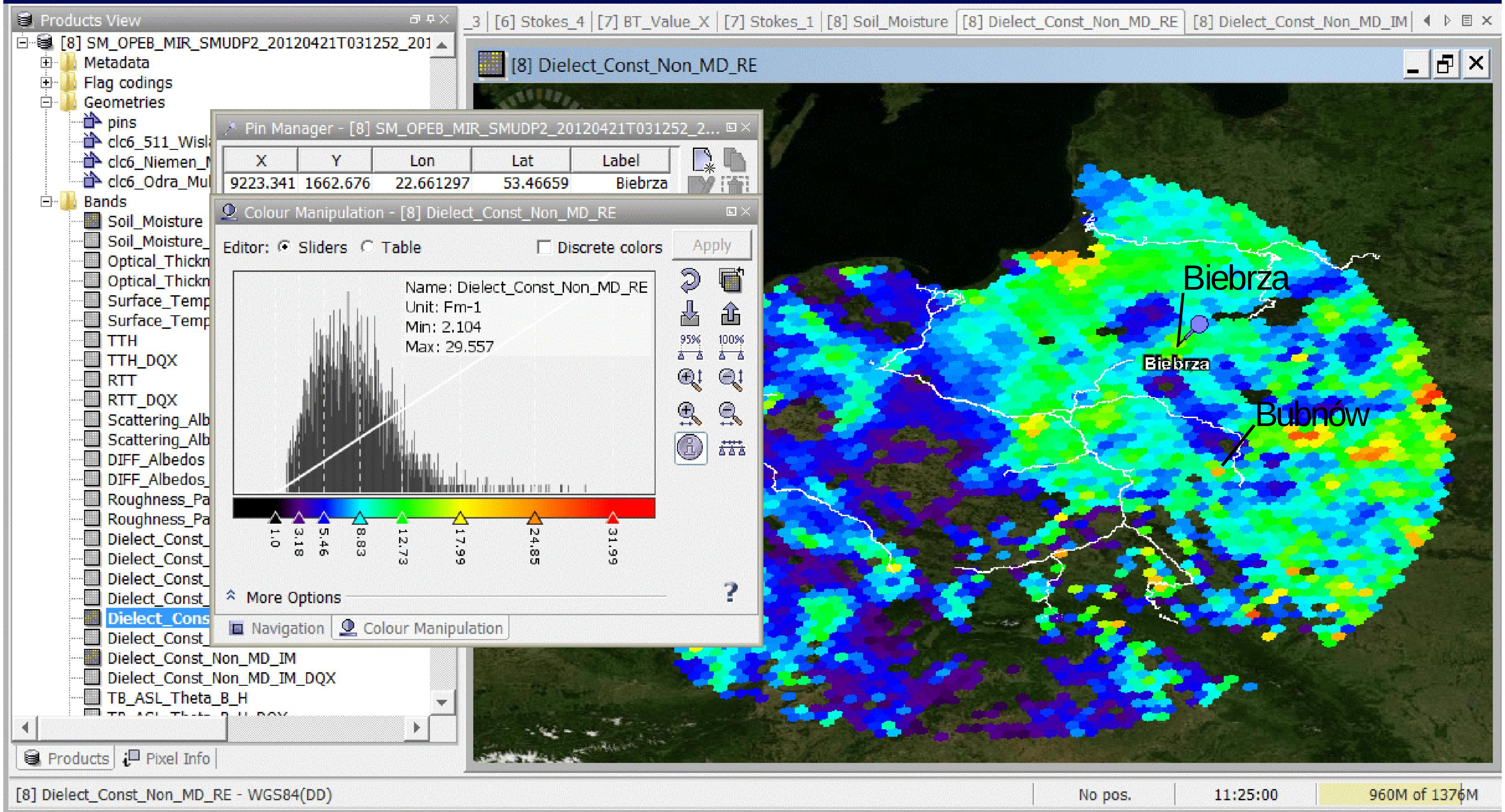
SM_OPEB_MIR_SCLF1C_20120421T035155_20120421T035524_505_118_1

SM Observations in real data L2



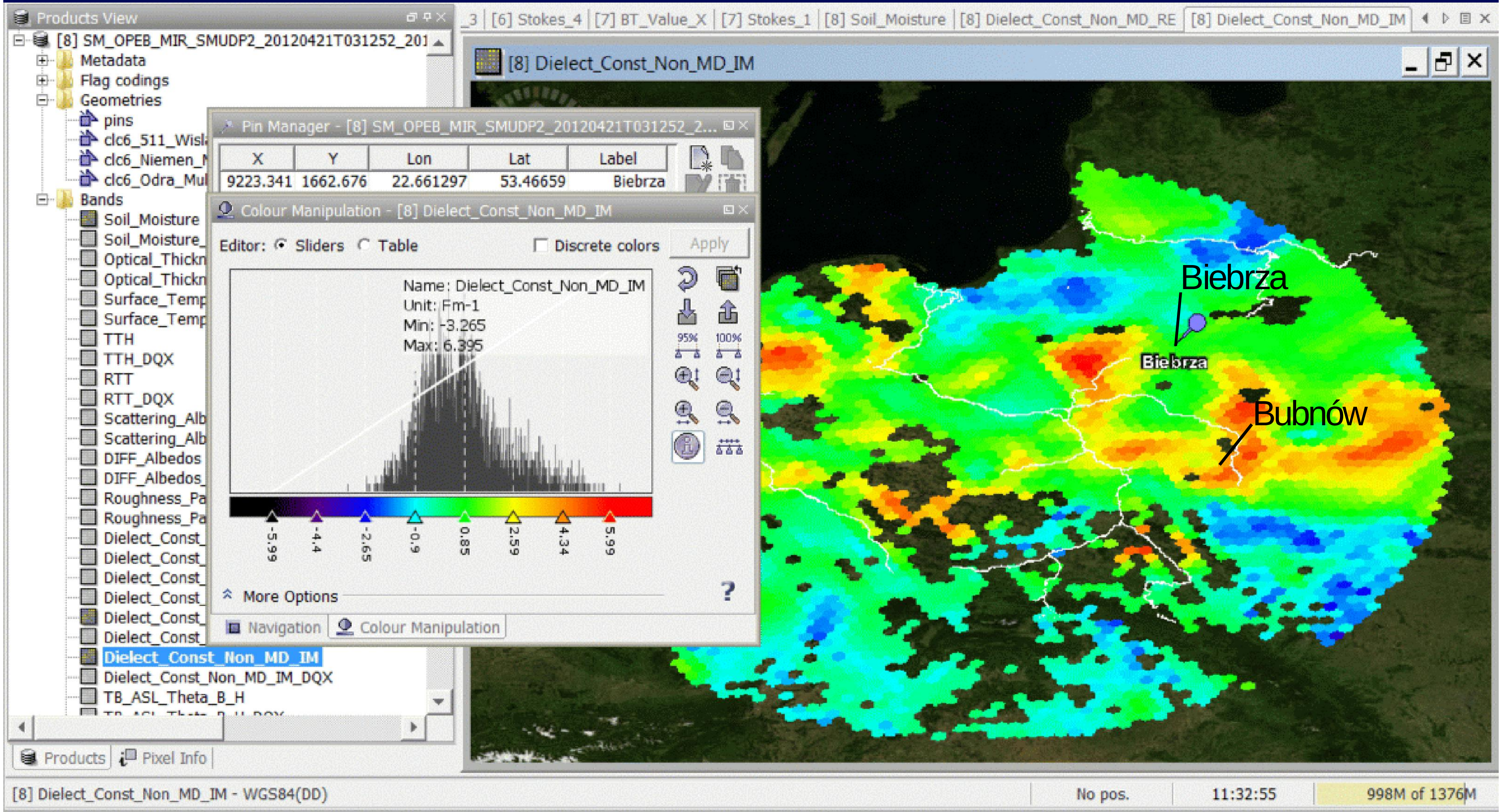
SM_OPEB_MIR_SMUDP2_20120421T031252_20120421T040611_500_118_1

Dielect_Const_Non_MD_RE in real data L2



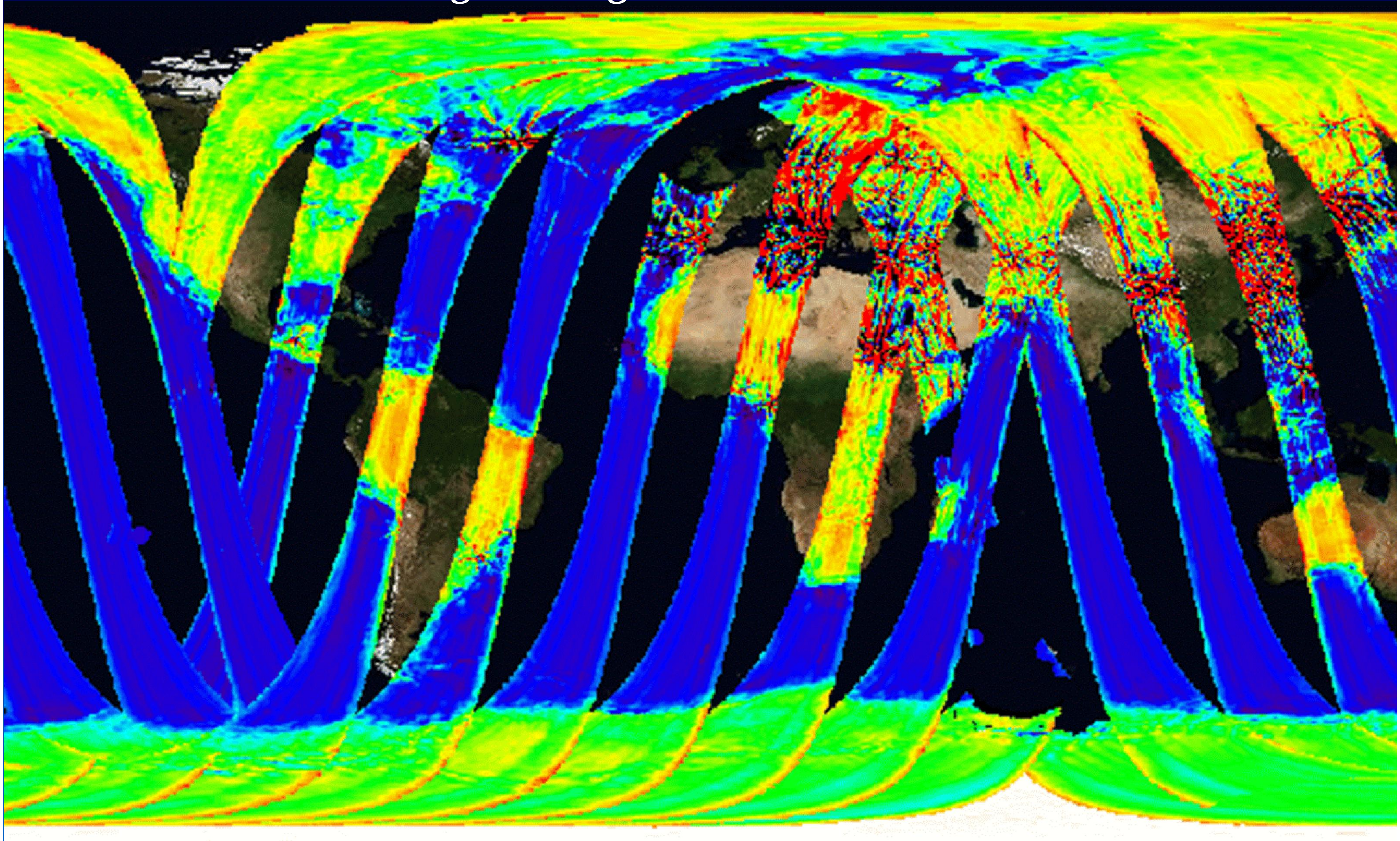
SM_OPEB_MIR_SMUDP2_20120421T031252_20120421T040611_500_118_1

Dielect_Const_Non_MD_IM in real data L2



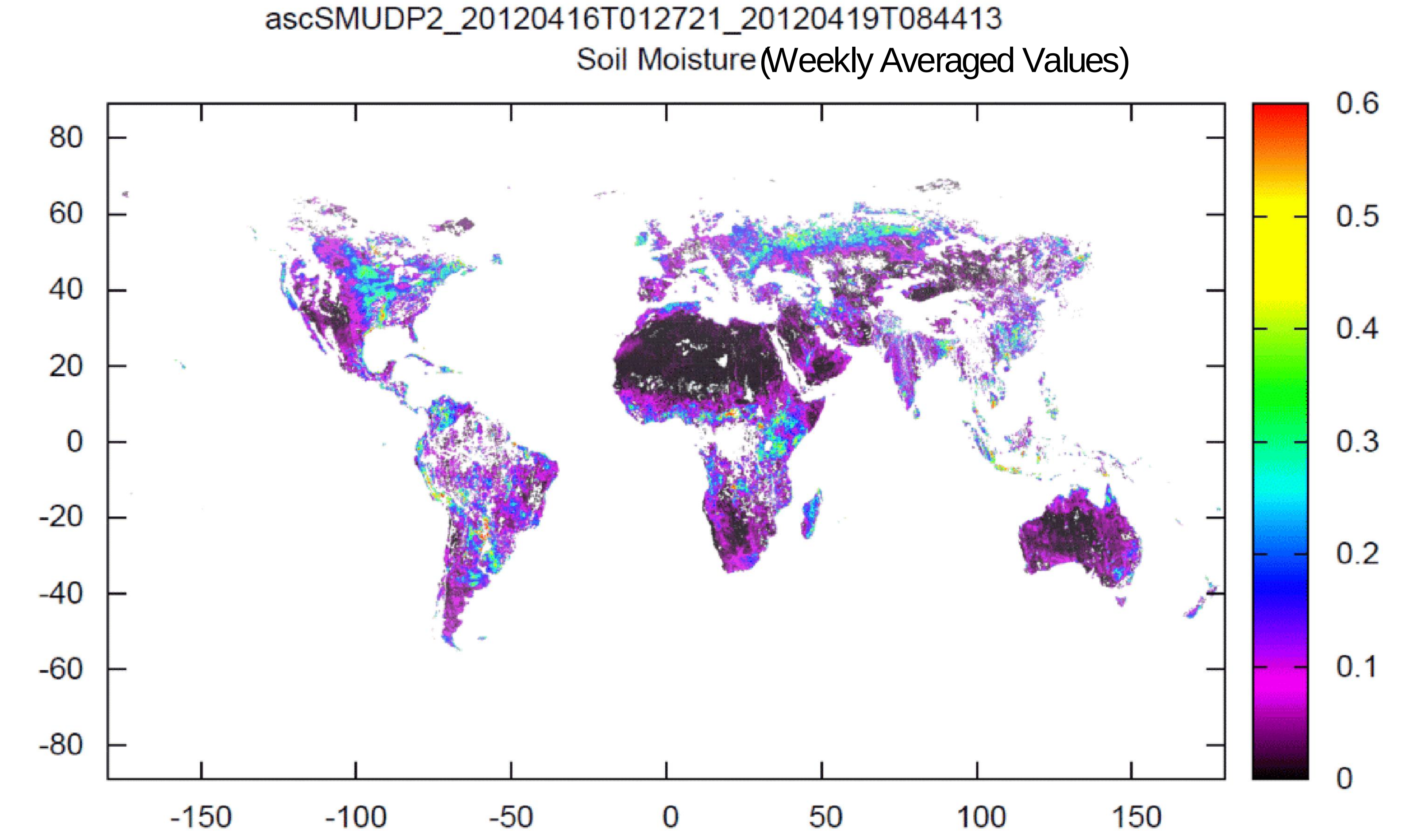
SM_OPEB_MIR_SMUDP2_20120421T031252_20120421T040611_500_118_1

FIRST global image /November-December 2009

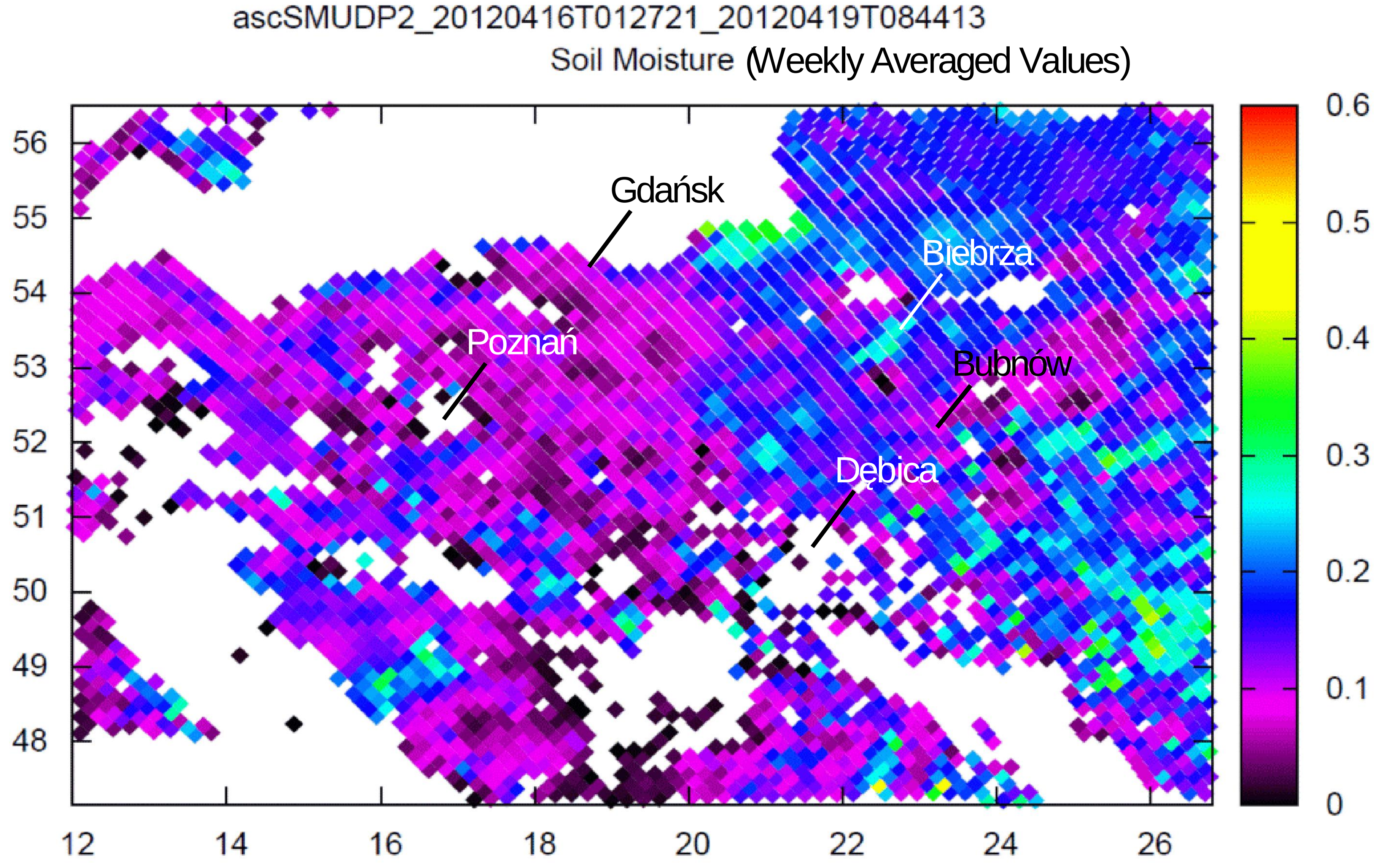


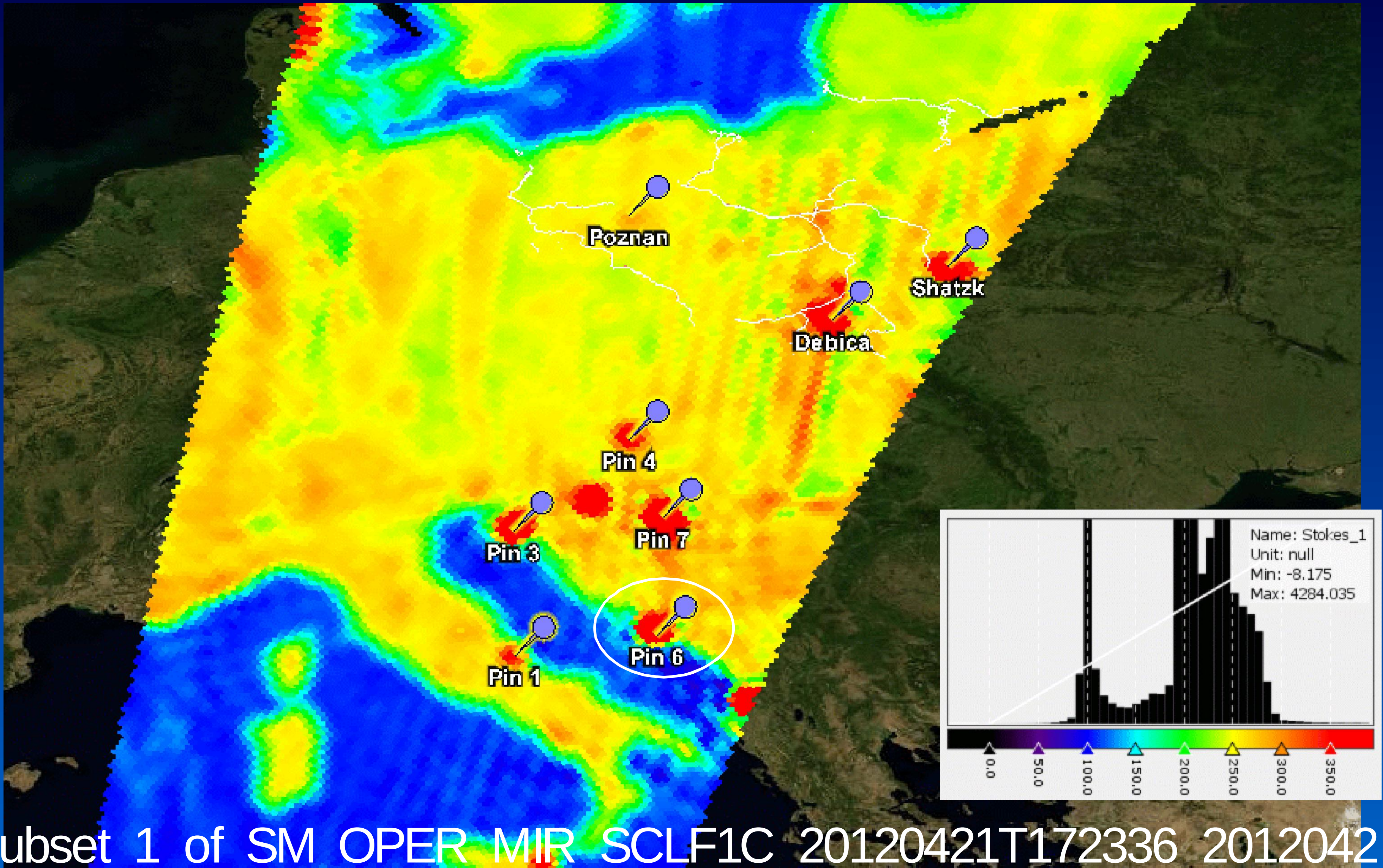
http://esamultimedia.esa.int/images/EarthObservation/SMOS_1st_IMAGE_2_H.png

L3 Global Product



L3 Regional Product





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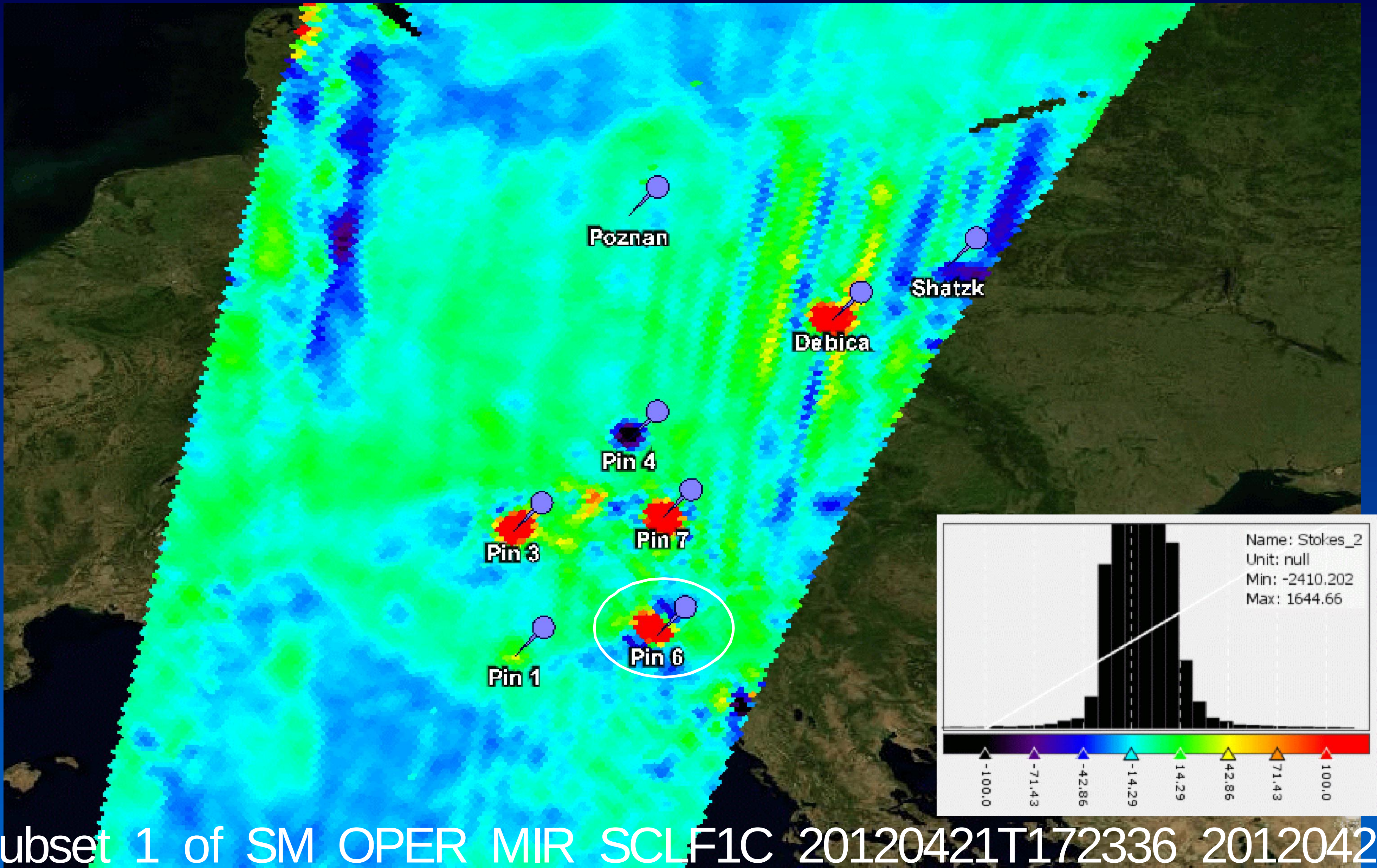

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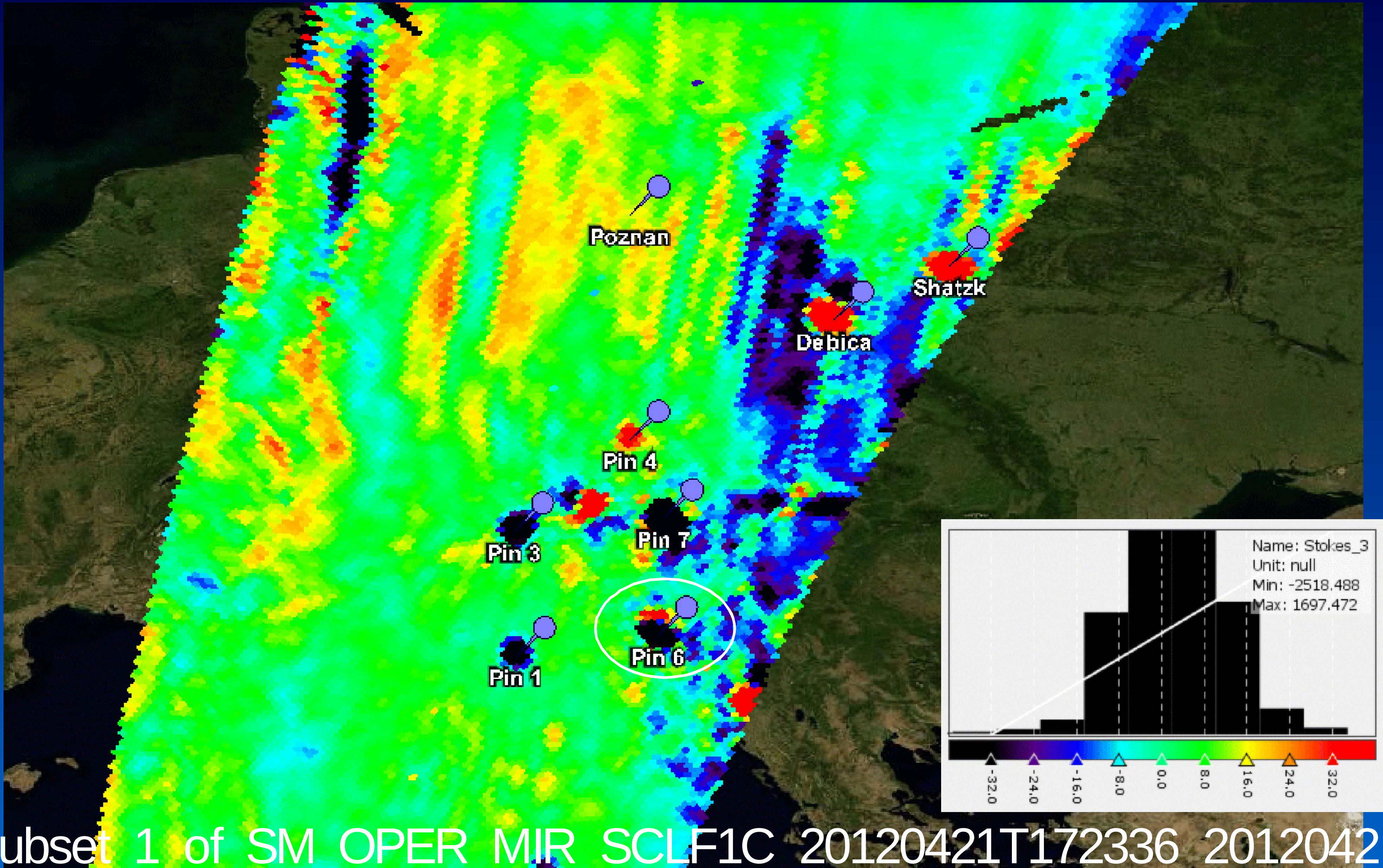

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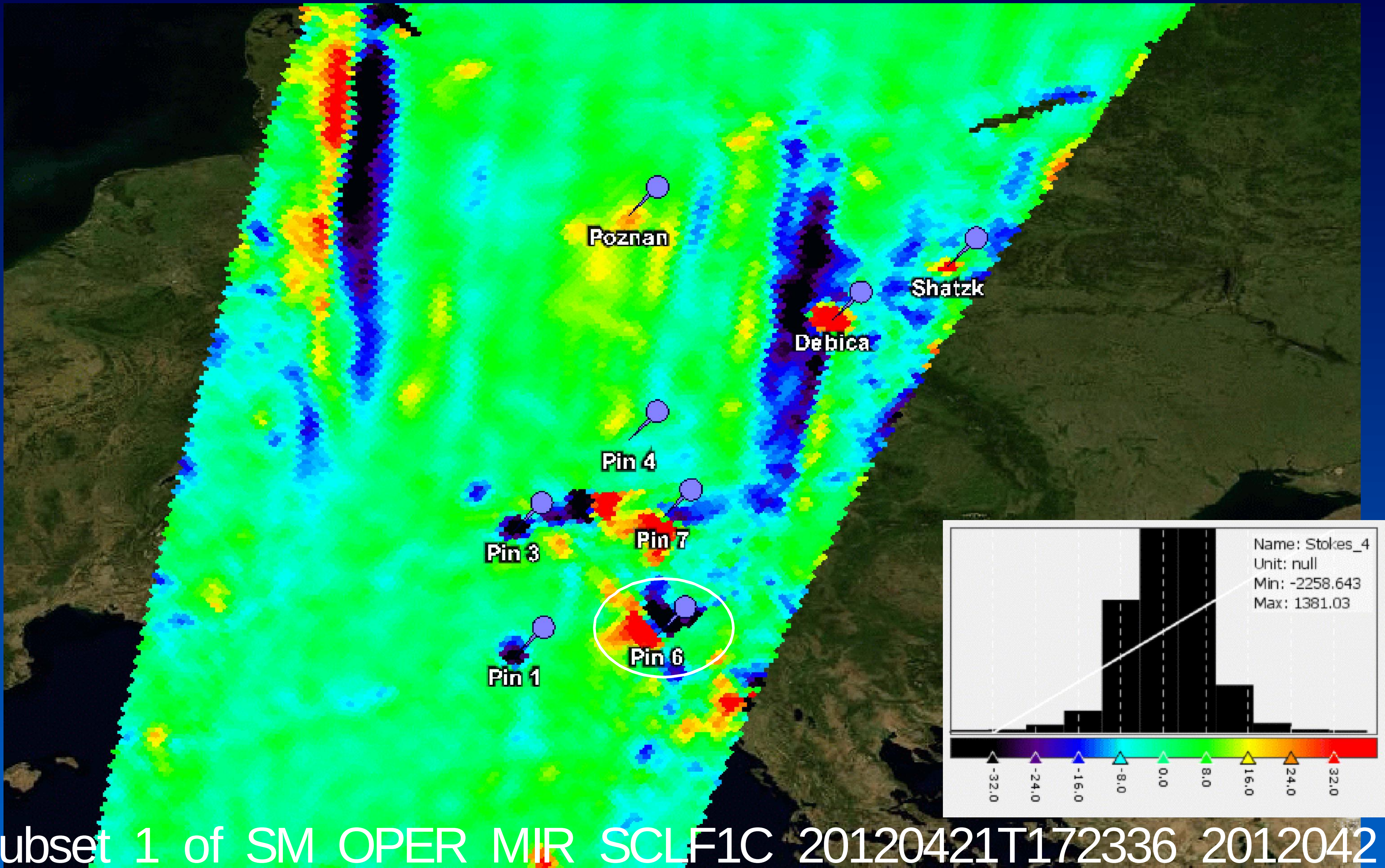

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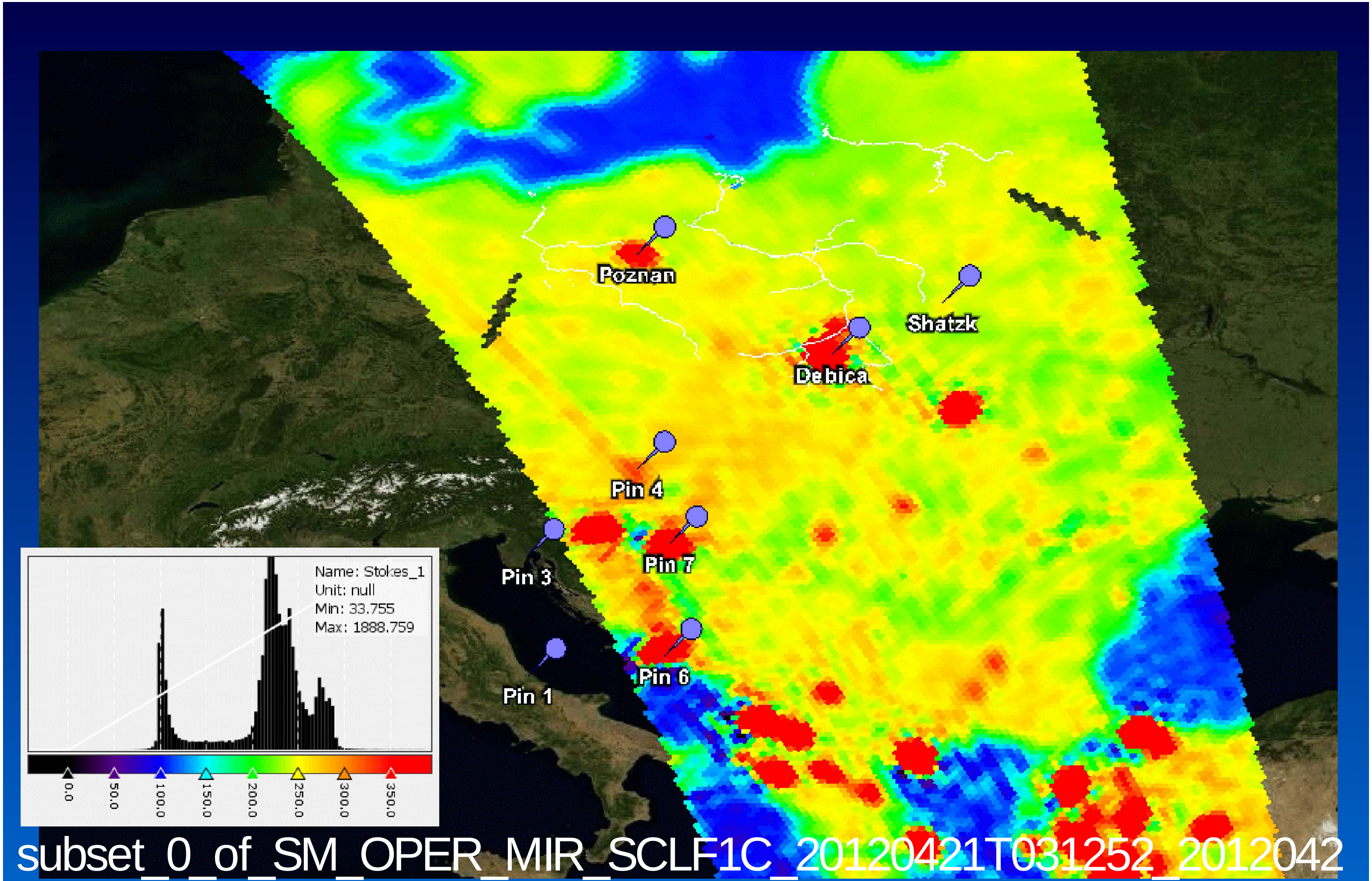

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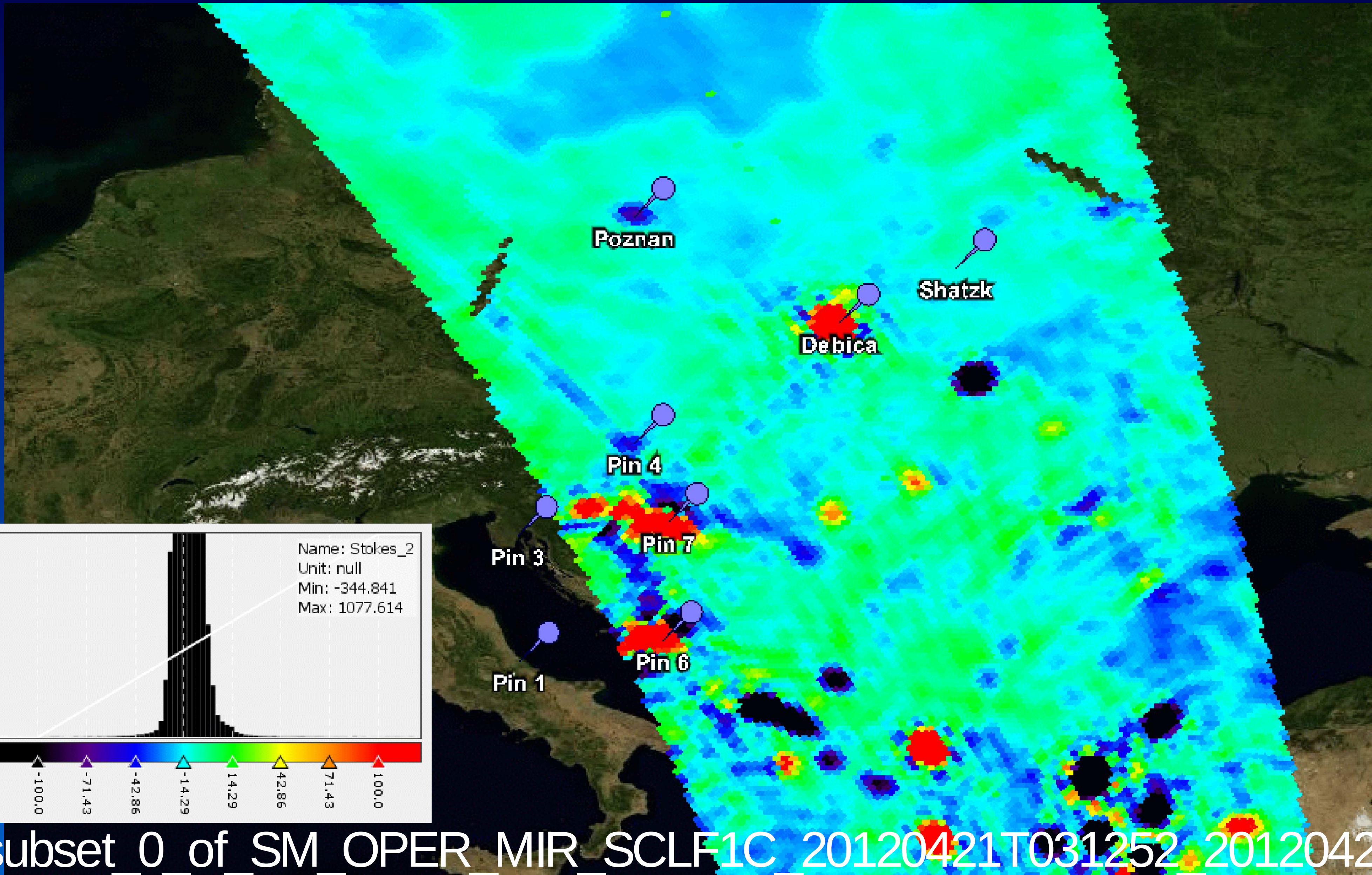

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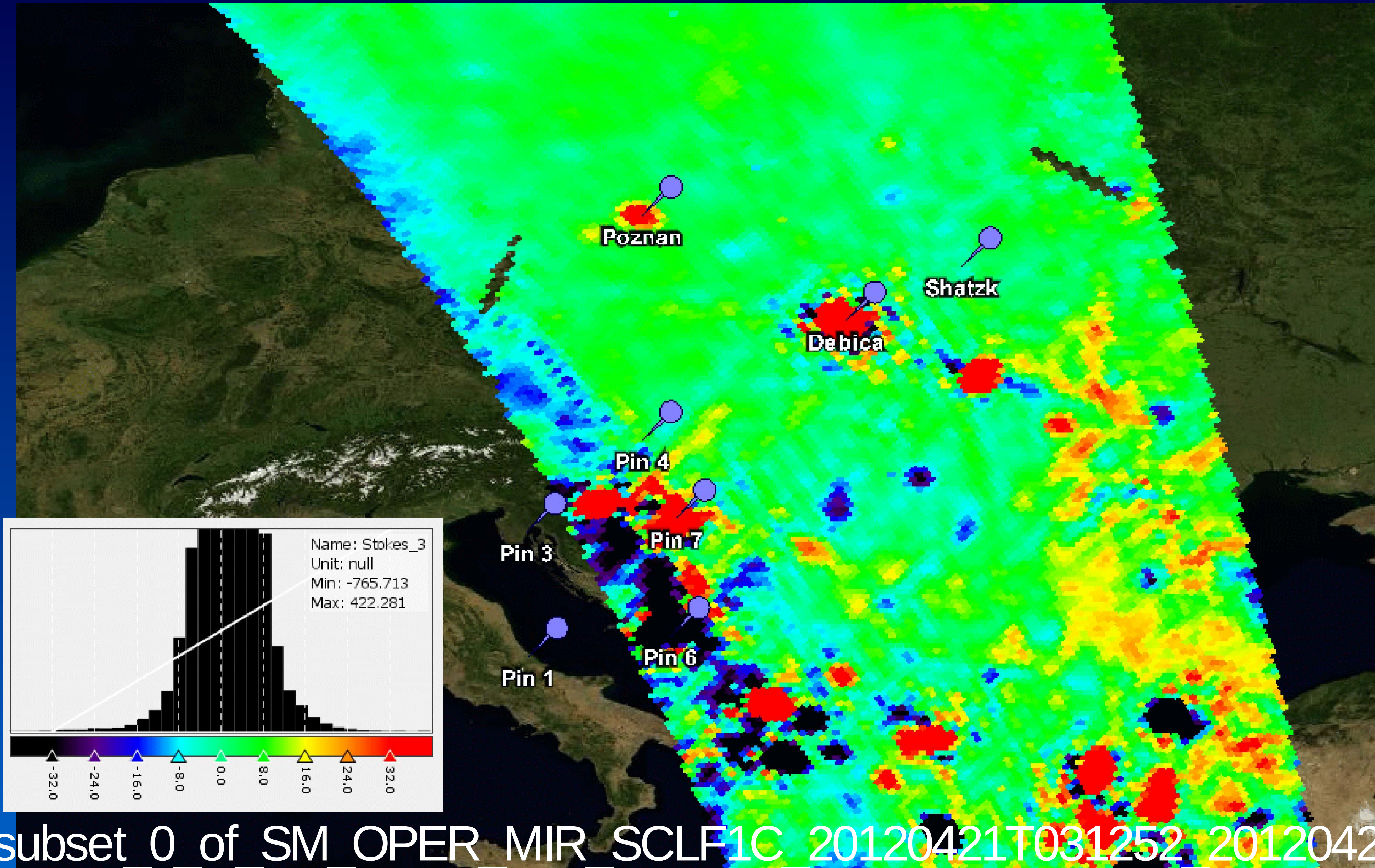

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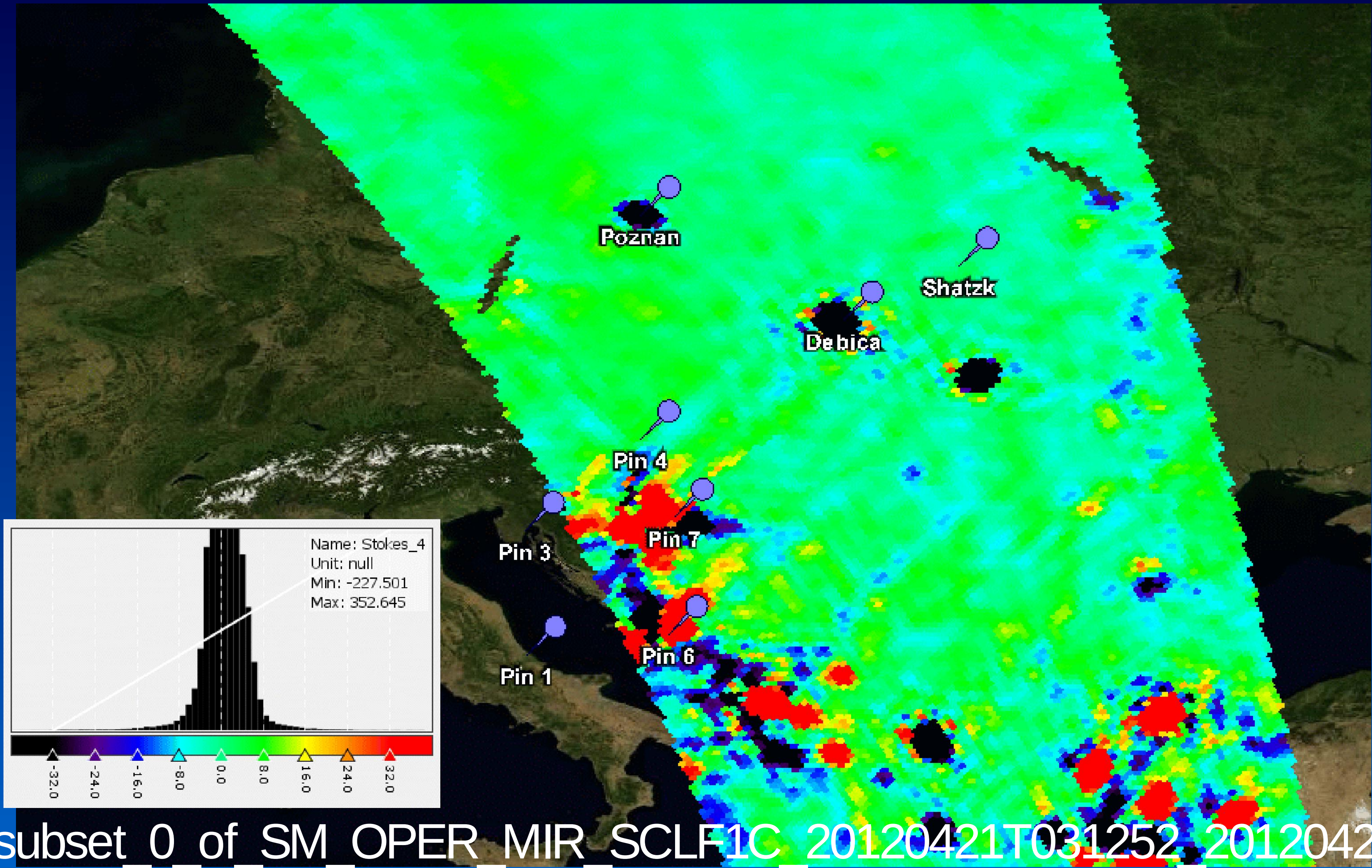
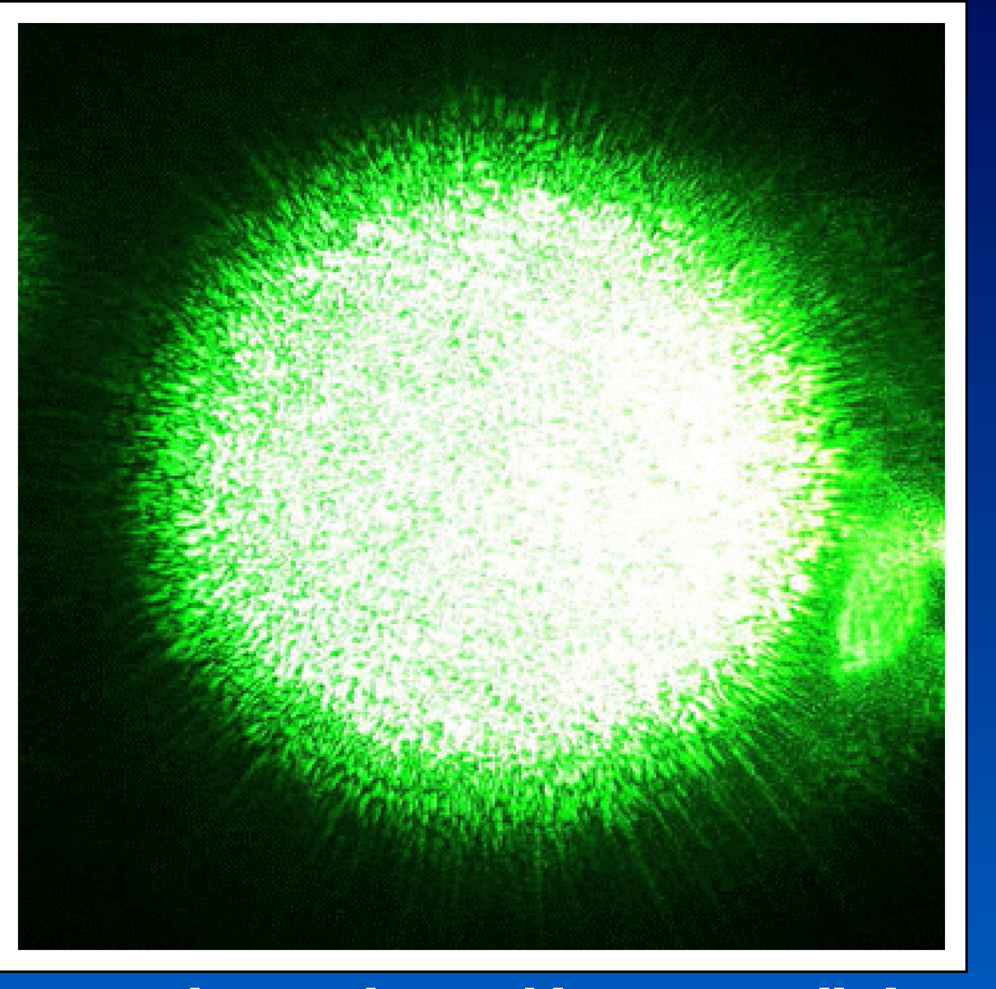


subset_0_of_SM_OPER_MIR_SCLF1C_20120421T031252_20120421T040611_505_001_1_Stokes_4

Speckle Effect in Coherent Leight

A speckle pattern is a random intensity pattern produced by the mutual interference of a set of wavefronts. This phenomenon has been investigated by scientists since the time of Newton, but speckles have come into prominence since the invention of the laser and have now found a variety of applications.



If the relative modal group velocities change with time, the speckle pattern will also change with time. If differential mode attenuation occurs, modal noise results.

Mueller Matrix in Antenna Temperature

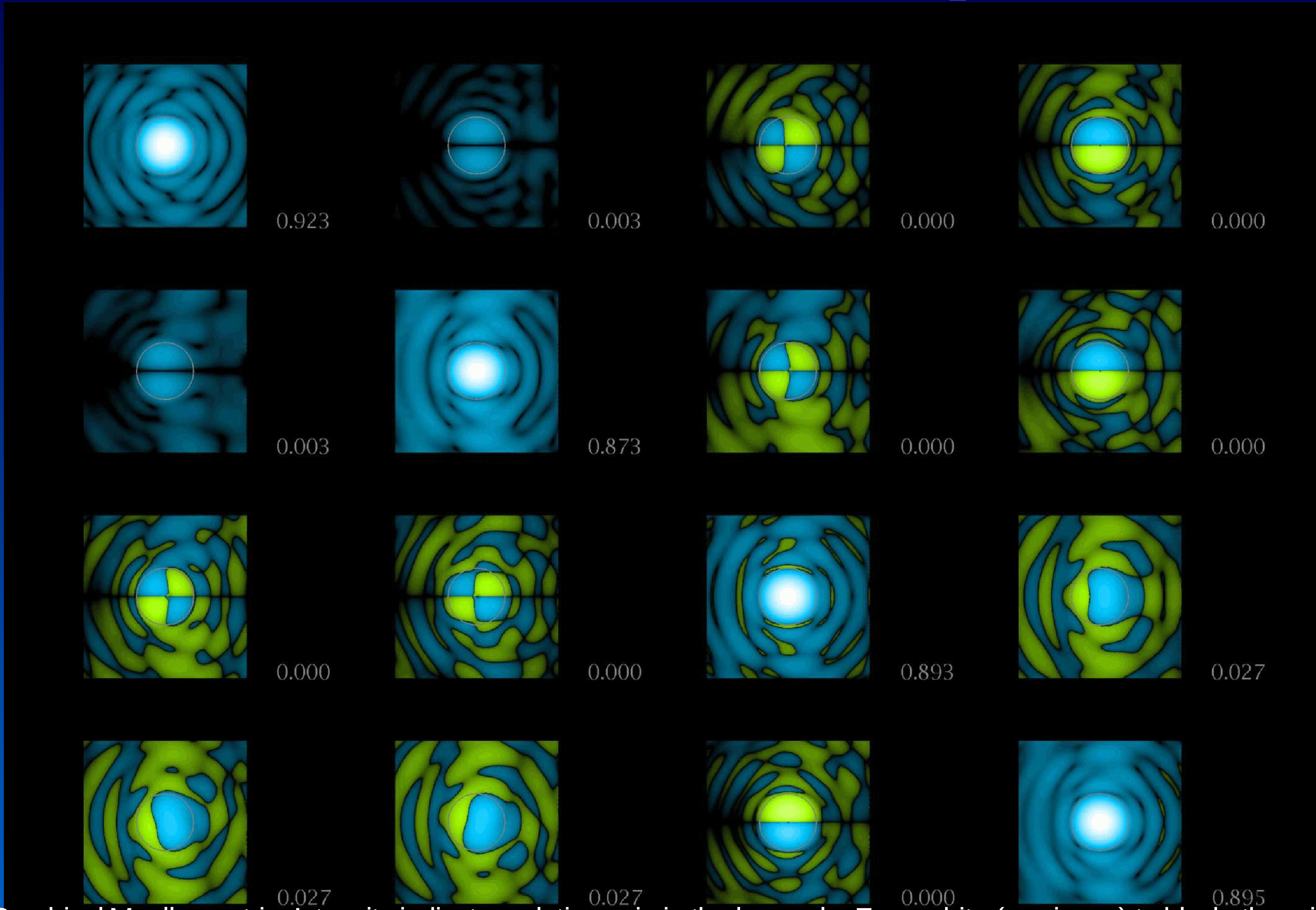
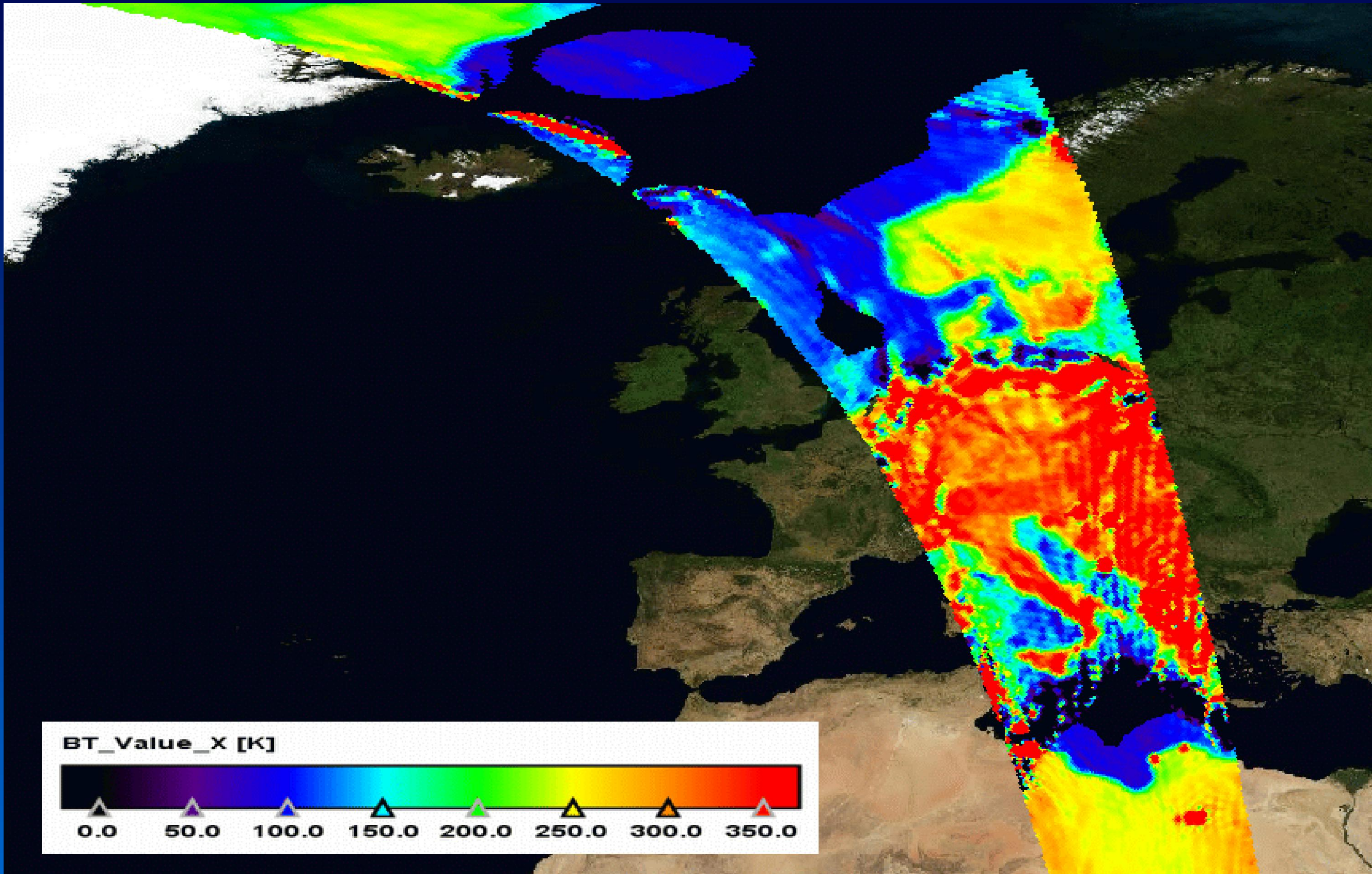
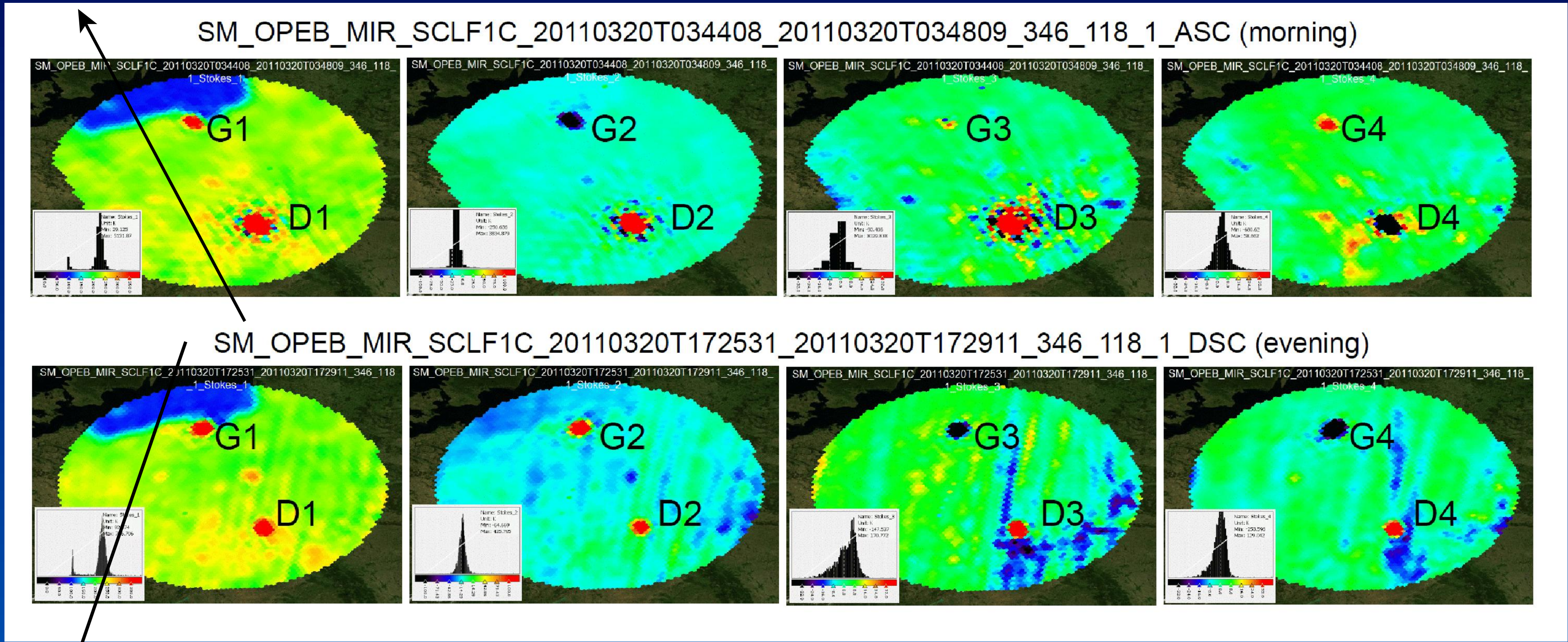


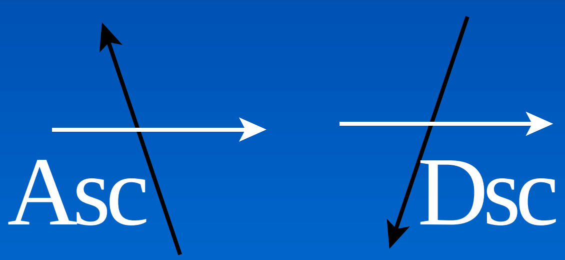
Fig. 2. Graphical Mueller matrix. Intensity indicates relative gain in the log scale. From white (maximum) to black, there is 60 dB of dynamic range. Blue hue: Positive values. Green hue: Negative values. Numbers: Results of integration over the main-beam region, as indicated by the light-gray circles. (Piepmeier J. Stokes_Antenna_Temperatures_101109TGRS2007909597)

RFI Flares



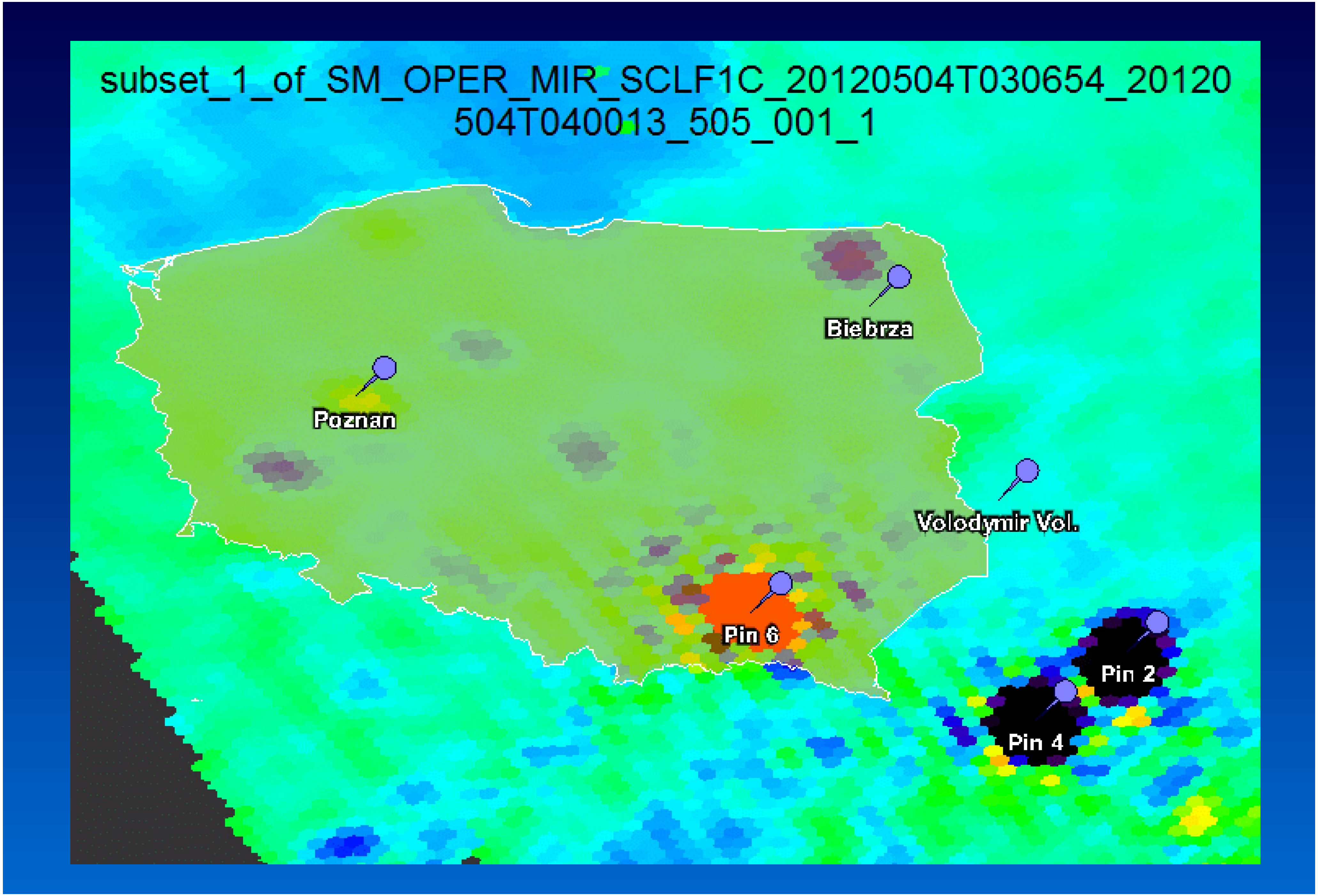
Observing Single Strong RFI in Poland





Differences are
- in magnitudes (background)
- in sign switching (strong RFIs)

That suggests spinorial behavior of observations.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Biebrza
Poznan
Volodymir Vol.
Pin 6
Pin 2
Pin 4