Improvement of CSP timeseries for Sahara by applying Quality control for satellite images

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Outline

- Status of the work
- Problem background
- Summary on existing timeseries issues
- Identifying the problems
- Proposed solutions
- Estimation of improvement upon quality control (QC)
- Outlook

Current status:

Final CSP timeseries for Sahara delivered to project partners

Background

- Irradiance for CSP timeseries for Sahara derived from Meteosat satellites
- 10 meteorological years were processed with
  - Meteosat First Generation (MFG) satellites (2003-2004)
  - Meteosat Second Generation (MSG) satellites (2005-2012)
- CSP timeseries produced with MSG satellites had some strange features
- Identifying and removing these issues are the focus of this talk

The timeseries behavior will be presented for the overlapping year 2005 using

MFG calculations as reference

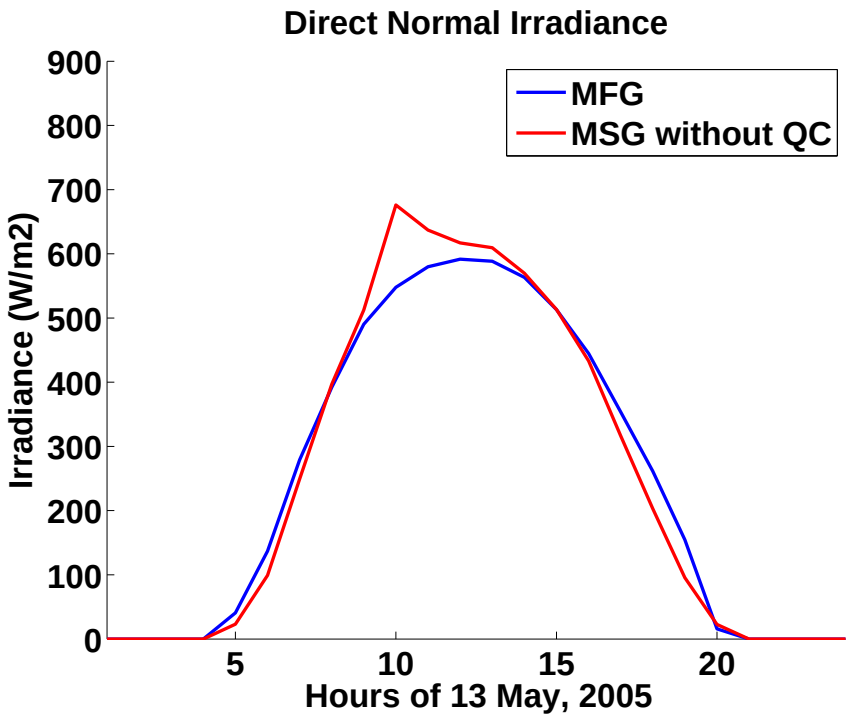
MFG & MSG for Sahara

- For Sahara, images from the narrowband of Meteosat satellite were taken because it has better coverage over Sahara than the HRV broadband channel
- However, the narrowband is more sensitive to anisotropic reflections than the broadband channel
- The algorithm for MFG retrieval had an atmospheric correction term included
- For MSG retrieval algorithm, no such atmospheric correction term yet implemented, mainly due to time constraint

Note: the atmospheric correction term is not the only difference between MFG and MSG satellites: their spatial and temporal resolutions are different and the algorithms are slightly different as well

Existing issues

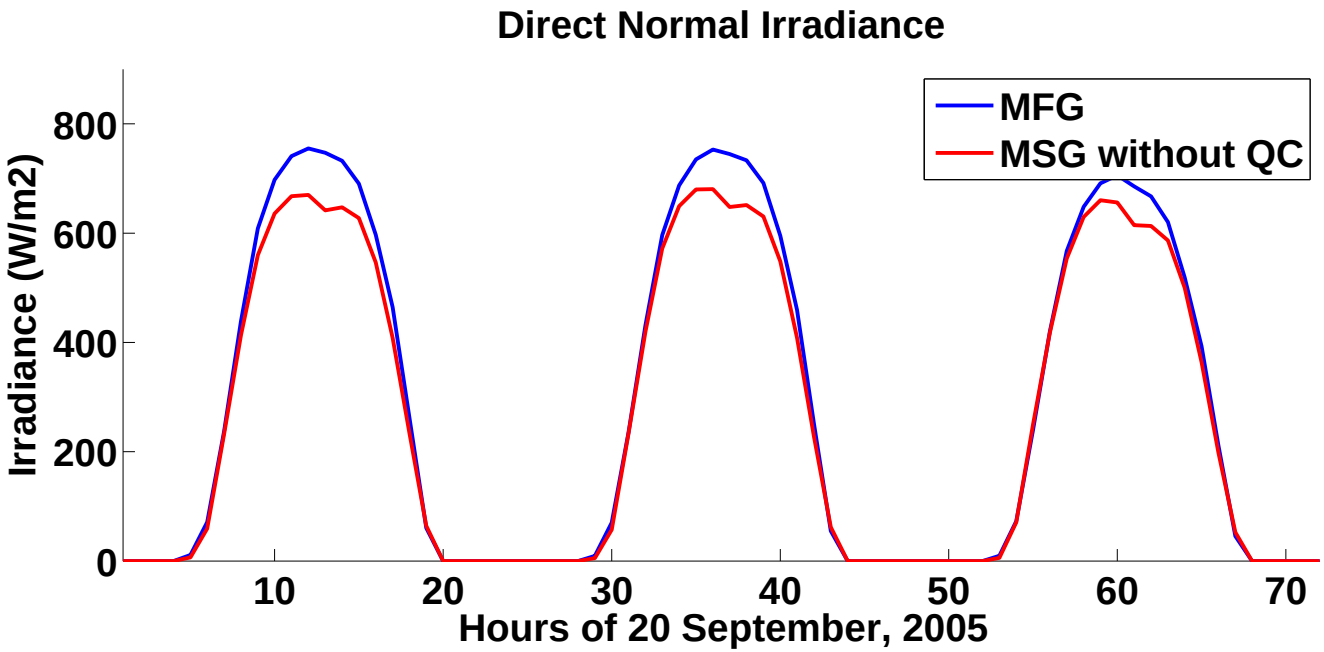
Frequent occurence of days with unusual shapes:



Since the timeseries does not refer to a single point, but results from spatial averaging, smooth patterns are expected.

Existing issues

Noon-time dips during Spring and Fall seasons:



Identifying the problems

Problem 1: Defective images

- Images with strange artifacts
  - data loss at specific image segment
  - data loss along image pixels
  - problem in one raw image may get transferred to all days of month
  - recurring strange patterns in images
- Issues with image headers
- Corrupted images can be few pixels shifted
- Complete day missing due to technical reasons

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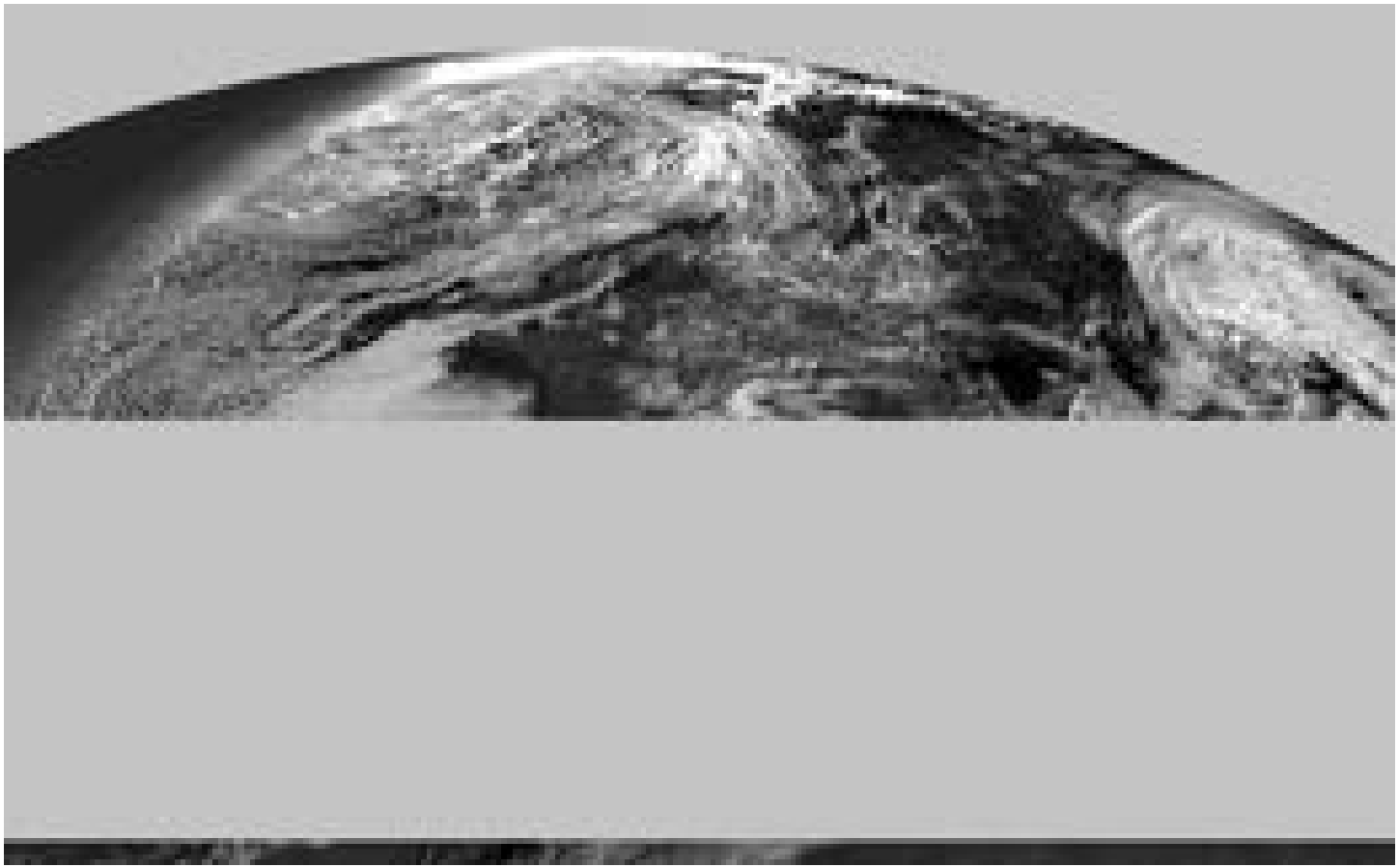
Missing image segment



Example cloudindex with lost data during 08:15 UTC of 28 February, 2005.

Identifying the problems

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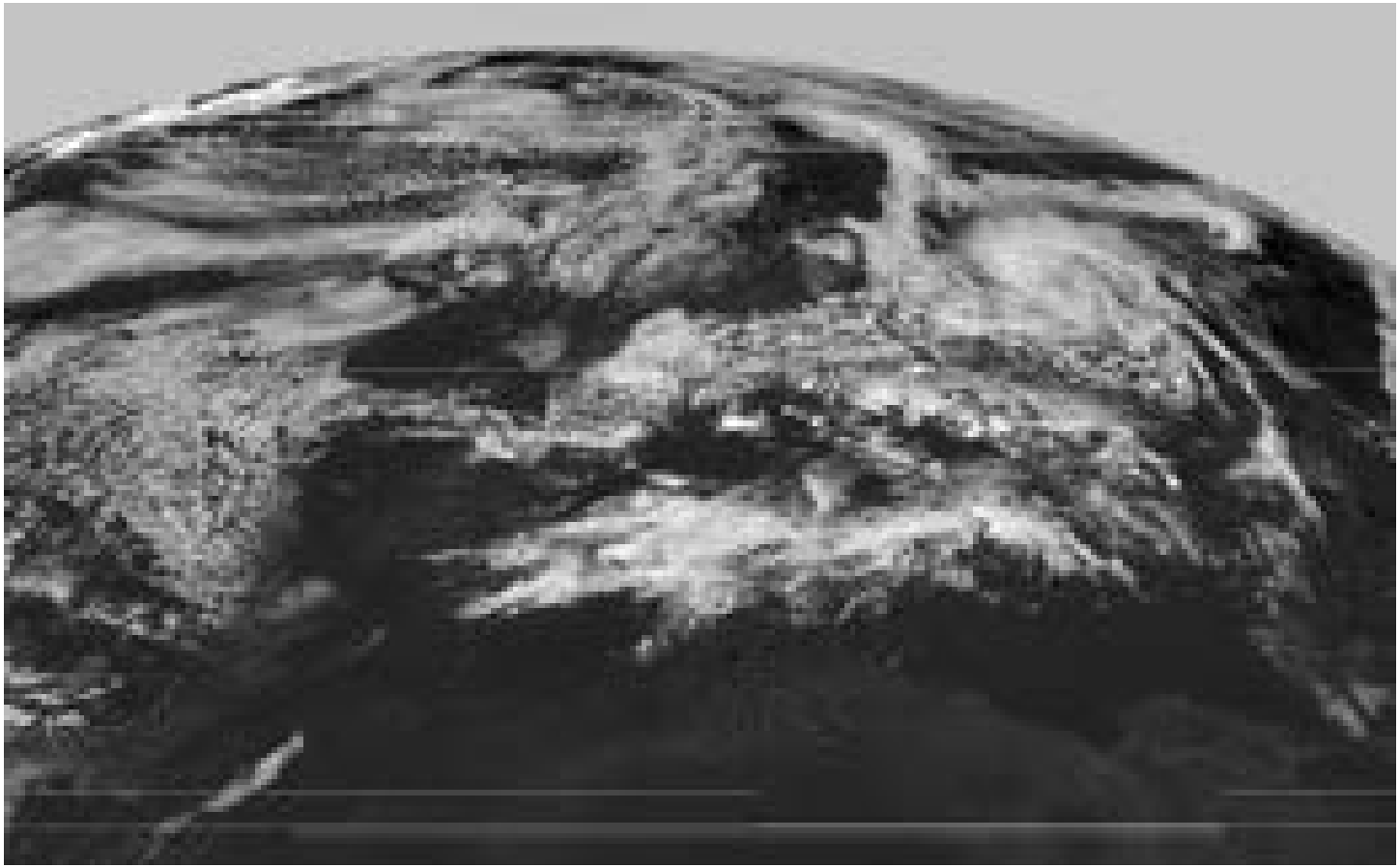
Data loss along image pixel



Example cloudindex with many artifacts during 11:15 UTC of 05 May, 2005. These artifacts remain for all days of the month.

Identifying the problems

Problem 1: Defective images

- Images with strange artifacts
  - data loss at specific image segment
  - data loss along image pixels
  - problem in one raw image may get transferred to all days of month
  - recurring strange patterns in images
- Issues with image headers
- Corrupted images can be few pixels shifted
- Complete day missing due to technical reasons

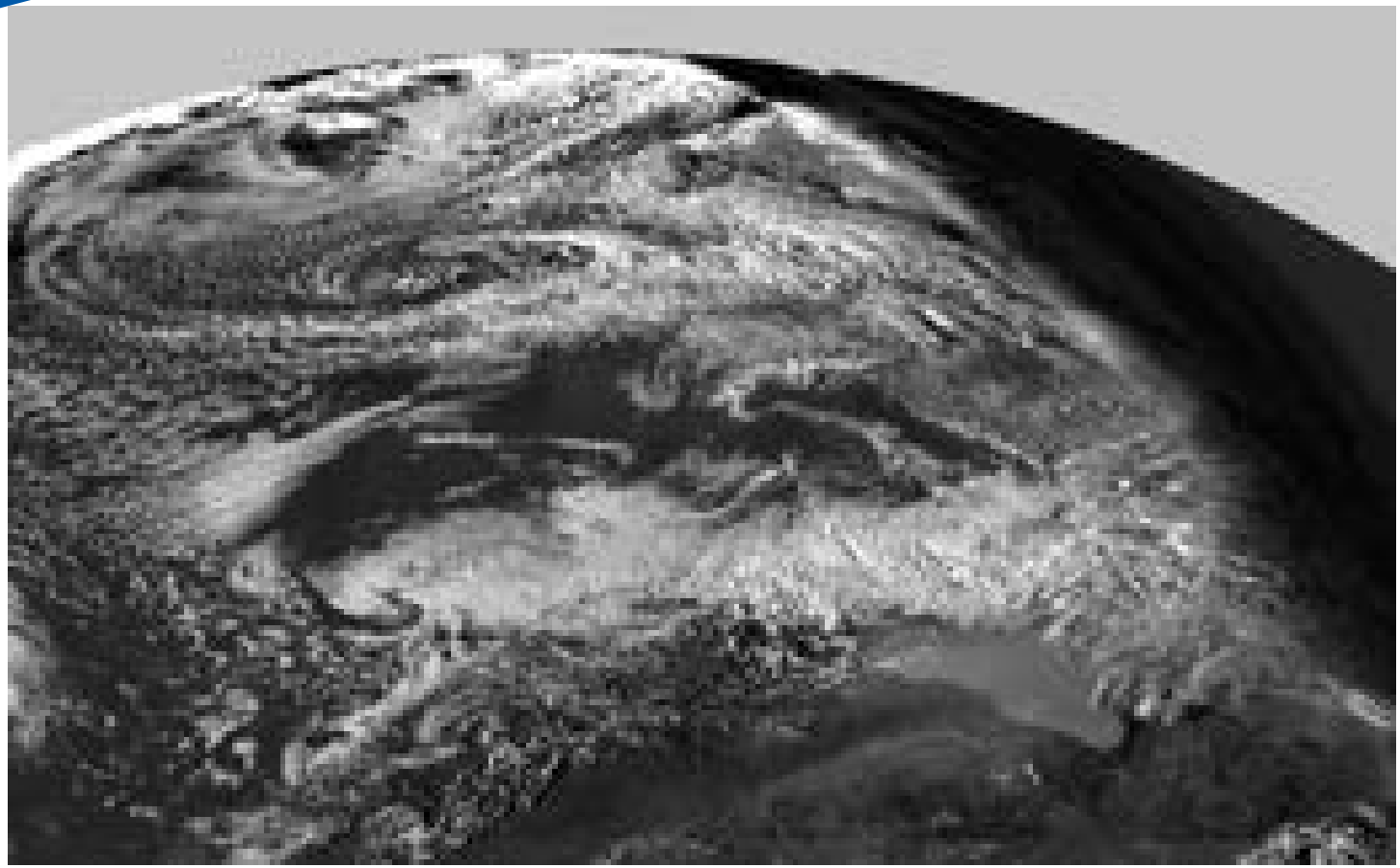


Figure: Cloudindex (date: 01 March, 2005 time: 1545 UTC)

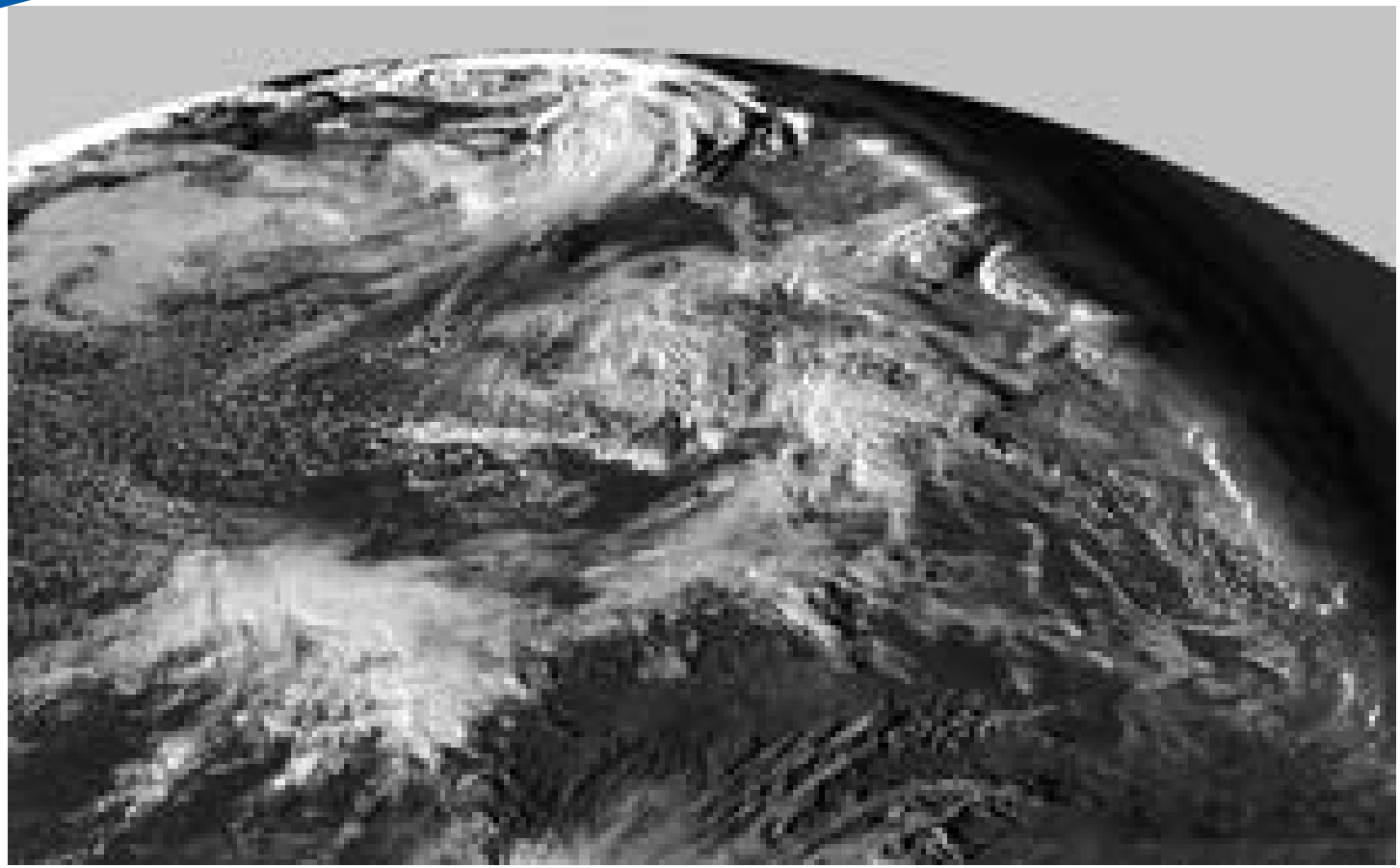


Figure: Cloudindex (date: 03 March, 2005 time: 1545 UTC)

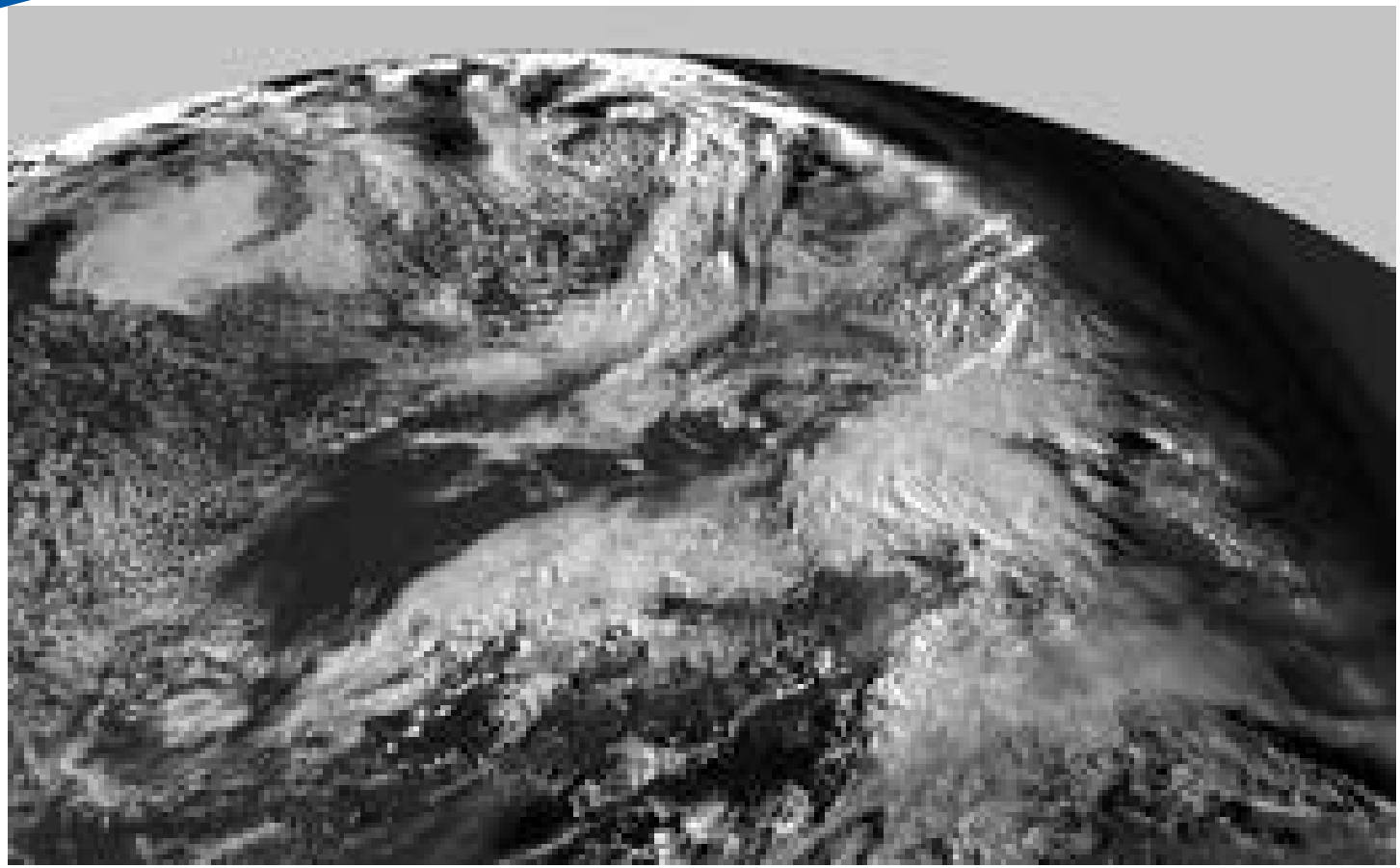


Figure: Cloudindex (date: 04 March, 2005 time: 1545 UTC)

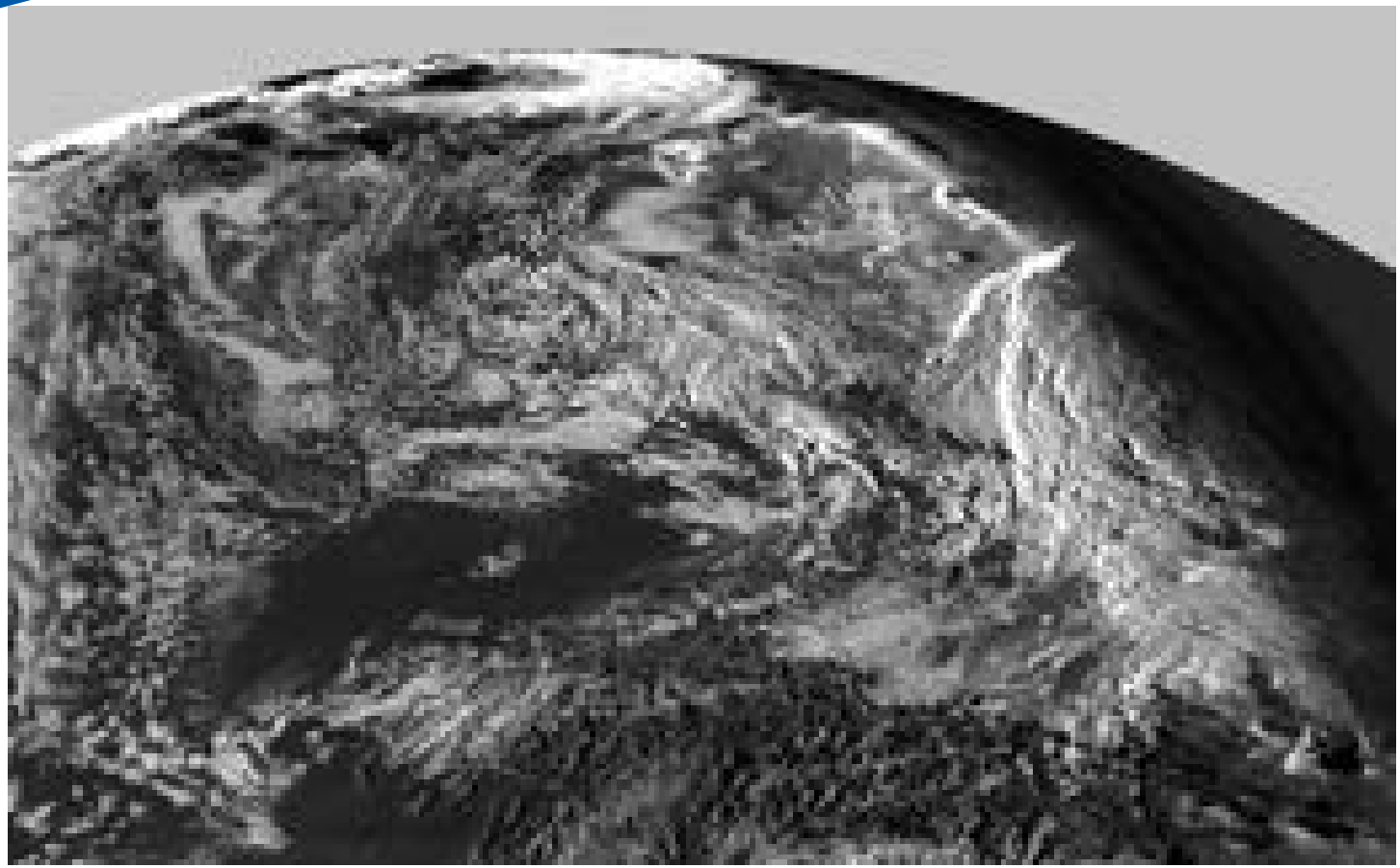


Figure: Cloudindex (date: 05 March, 2005 time: 1545 UTC)

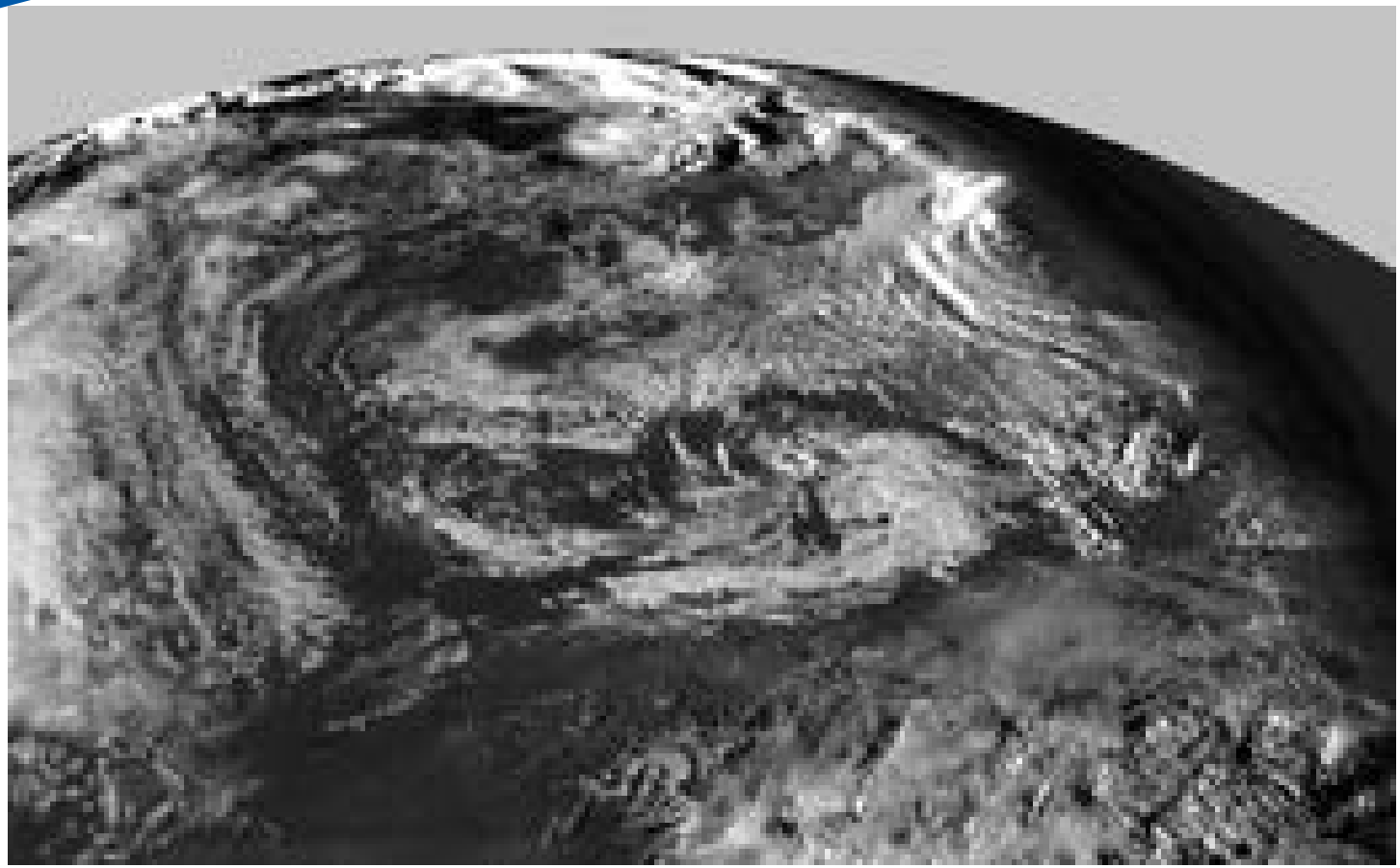


Figure: Cloudindex (date: 06 March, 2005 time: 1545 UTC)

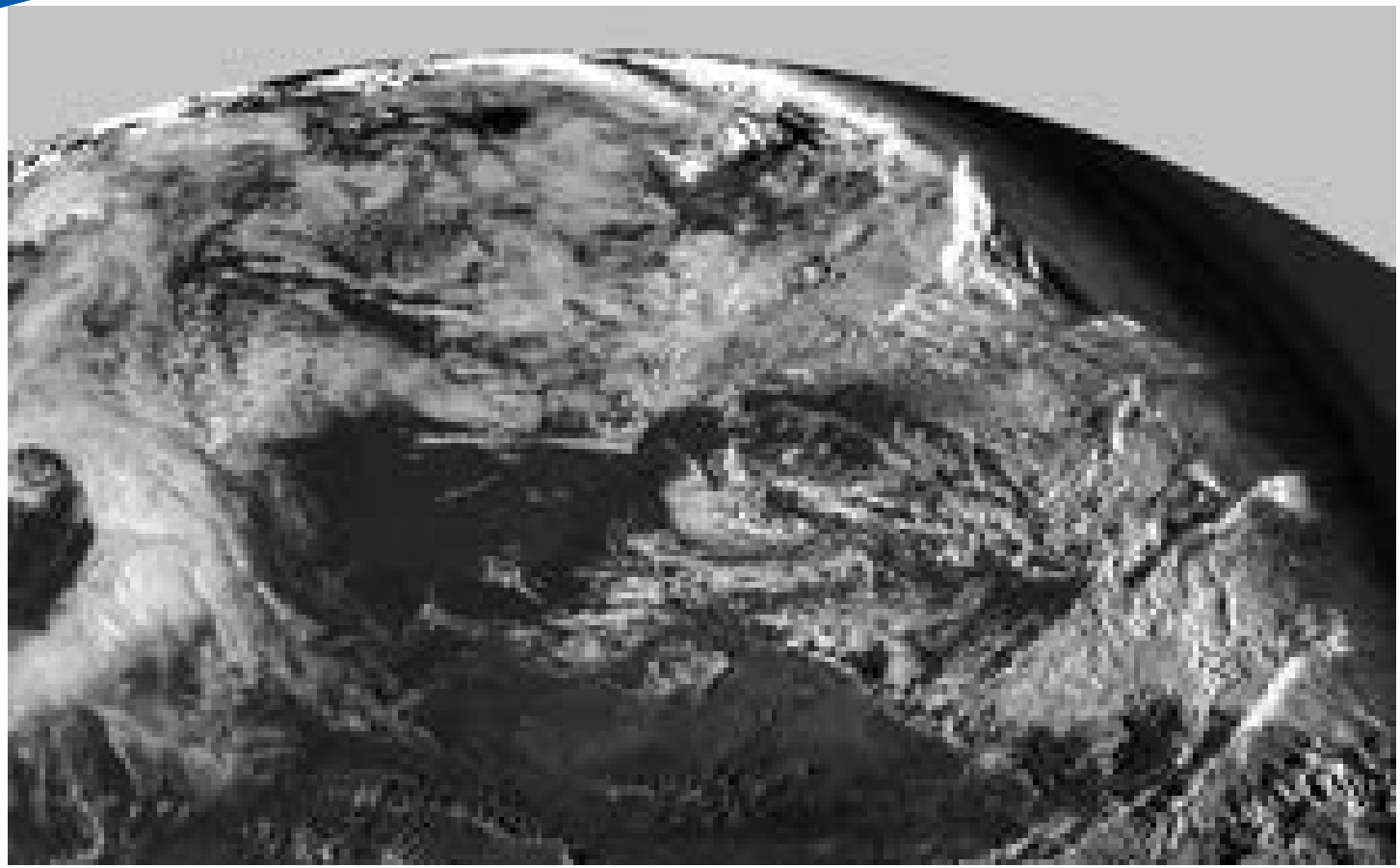


Figure: Cloudindex (date: 07 March, 2005 time: 1545 UTC)

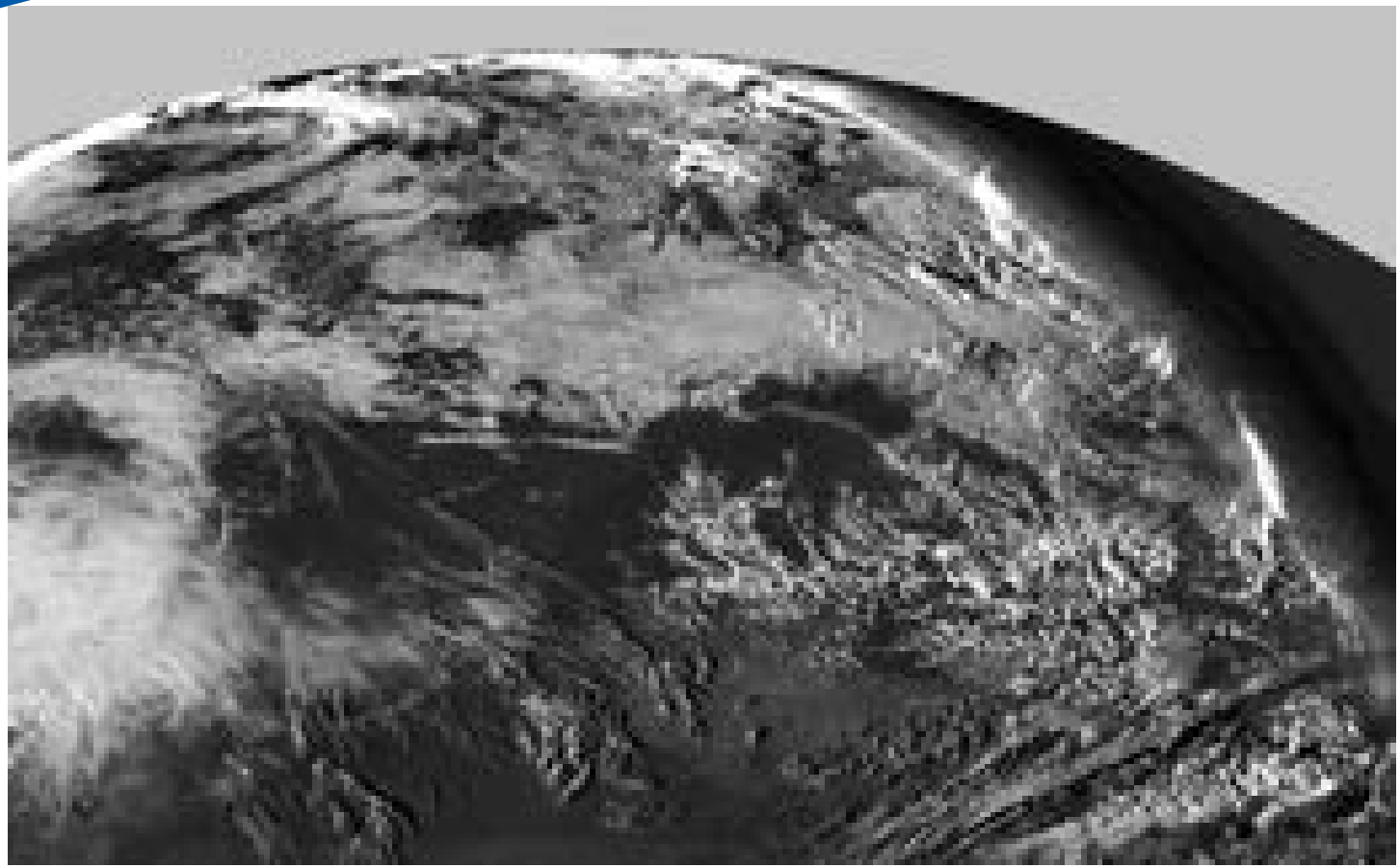


Figure: Cloudindex (date: 08 March, 2005 time: 1545 UTC)

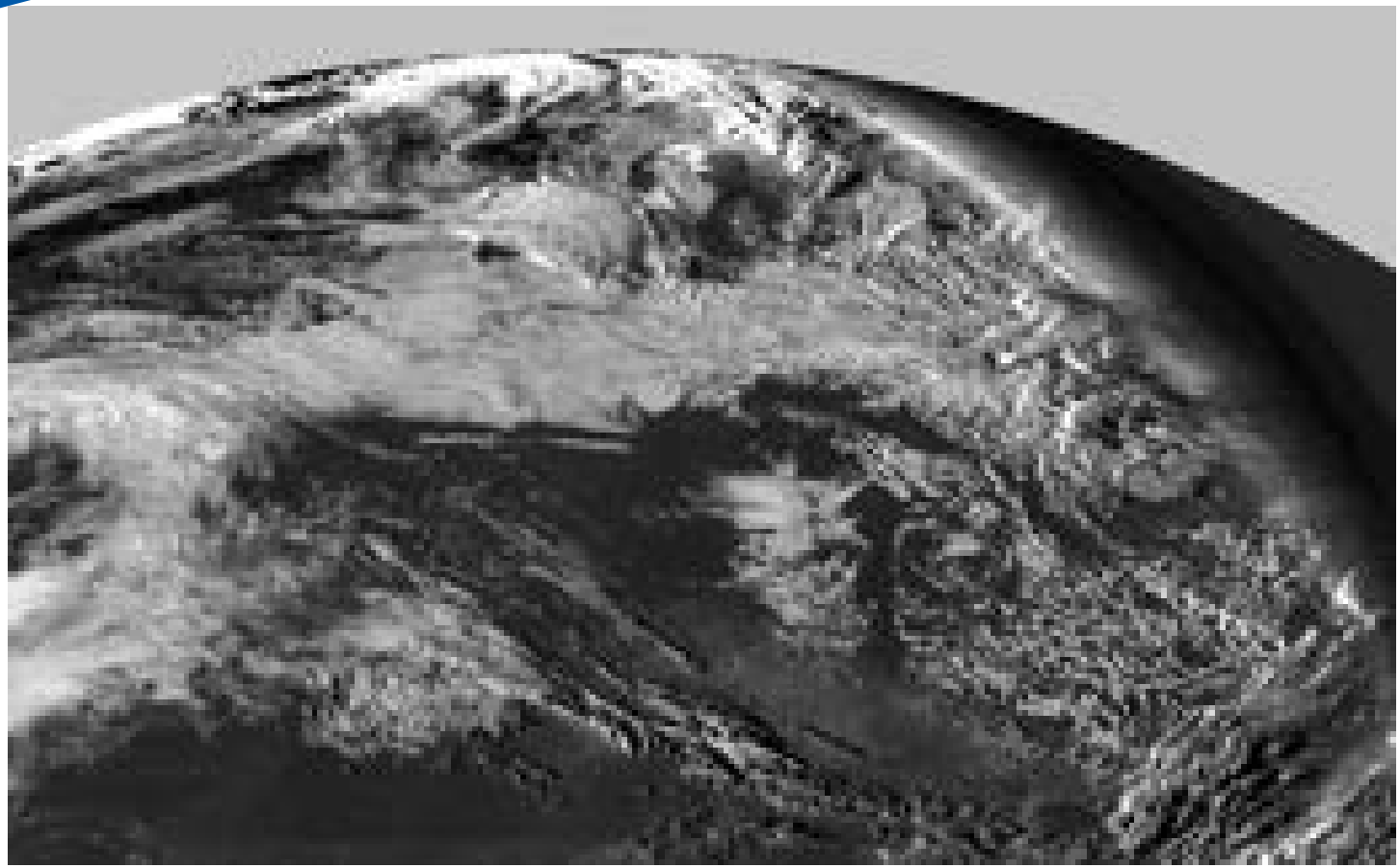


Figure: Cloudindex (date: 09 March, 2005 time: 1545 UTC)

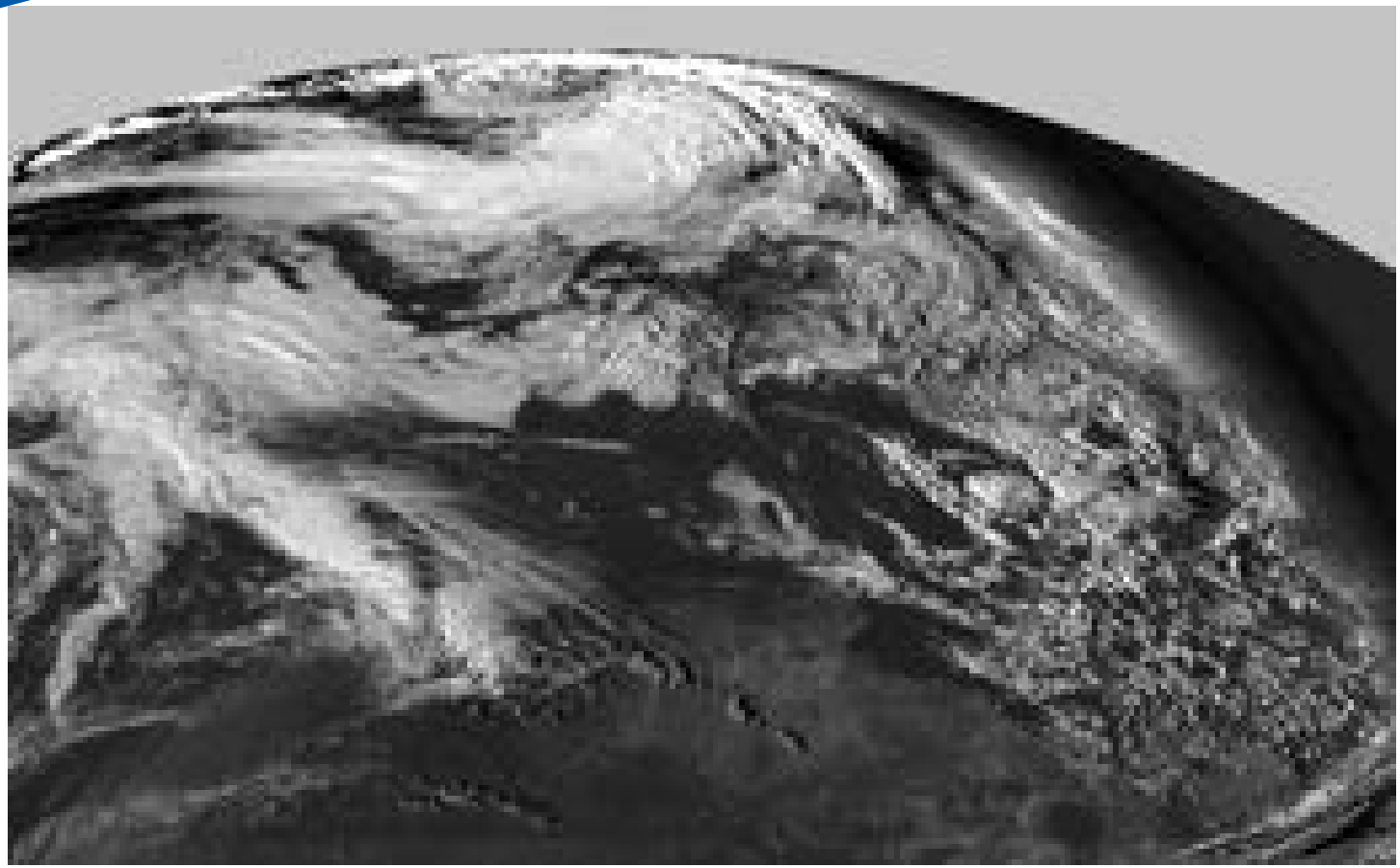


Figure: Cloudindex (date: 10 March, 2005 time: 1545 UTC)

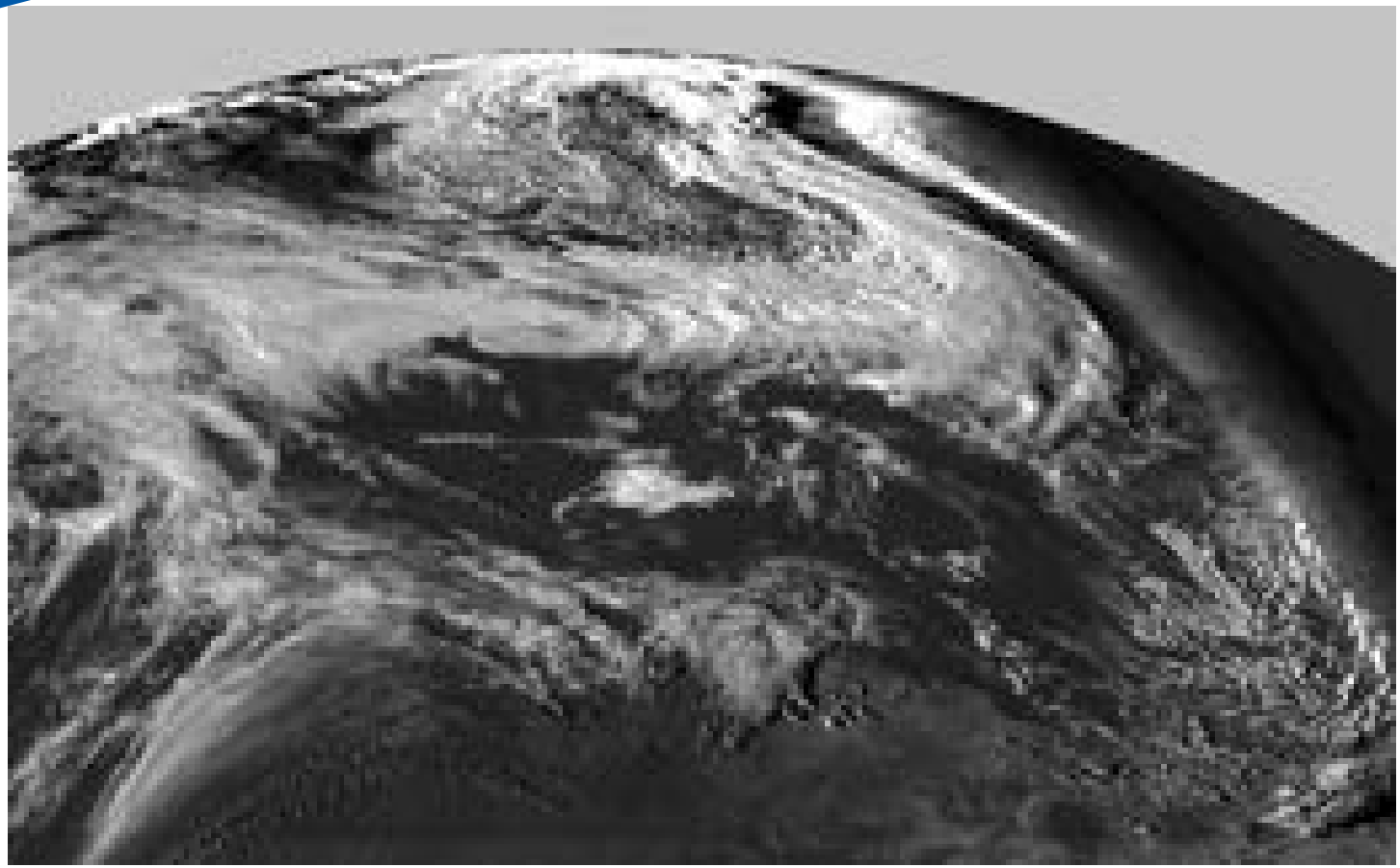


Figure: Cloudindex (date: 11 March, 2005 time: 1545 UTC)

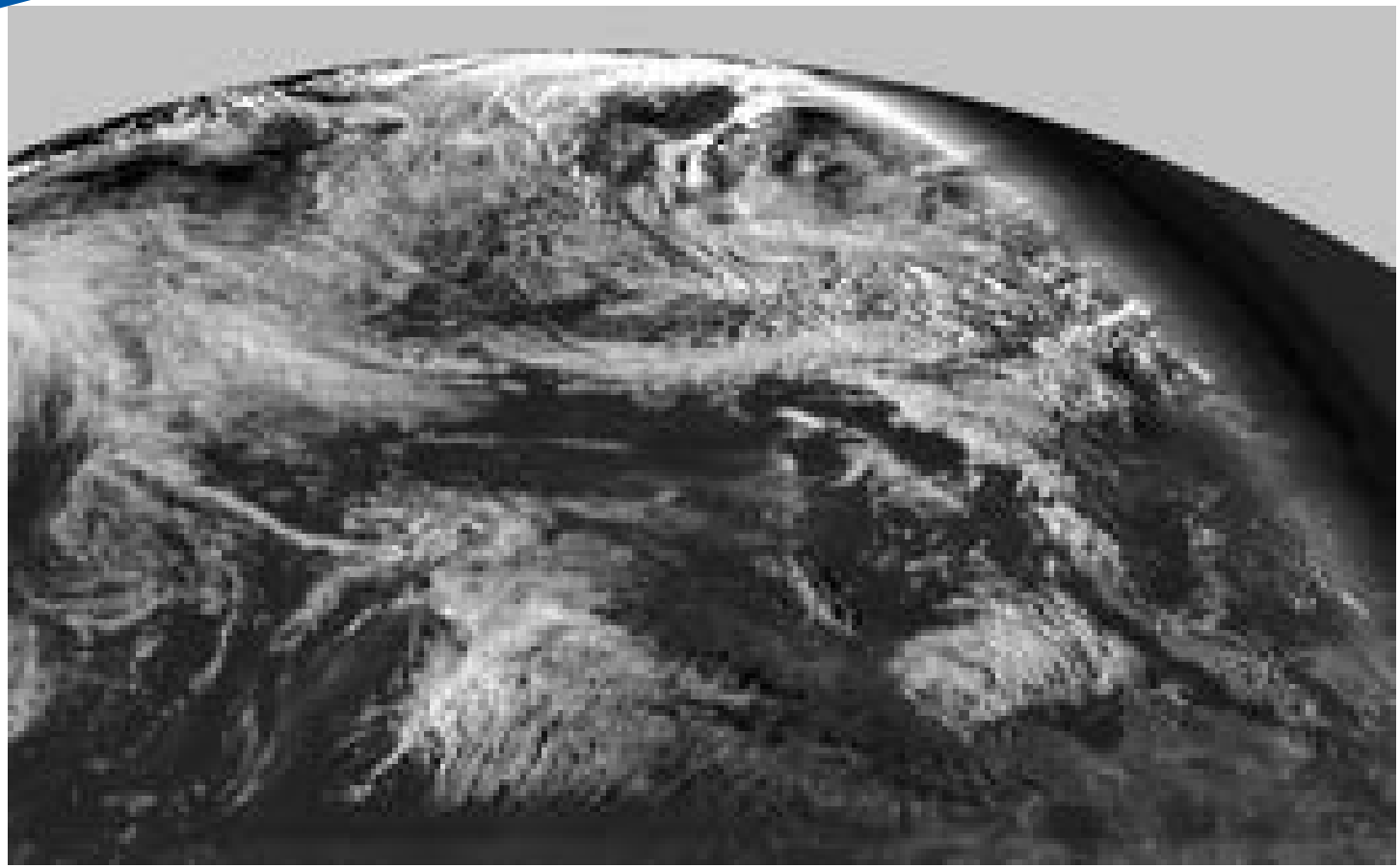


Figure: Cloudindex (date: 12 March, 2005 time: 1545 UTC)

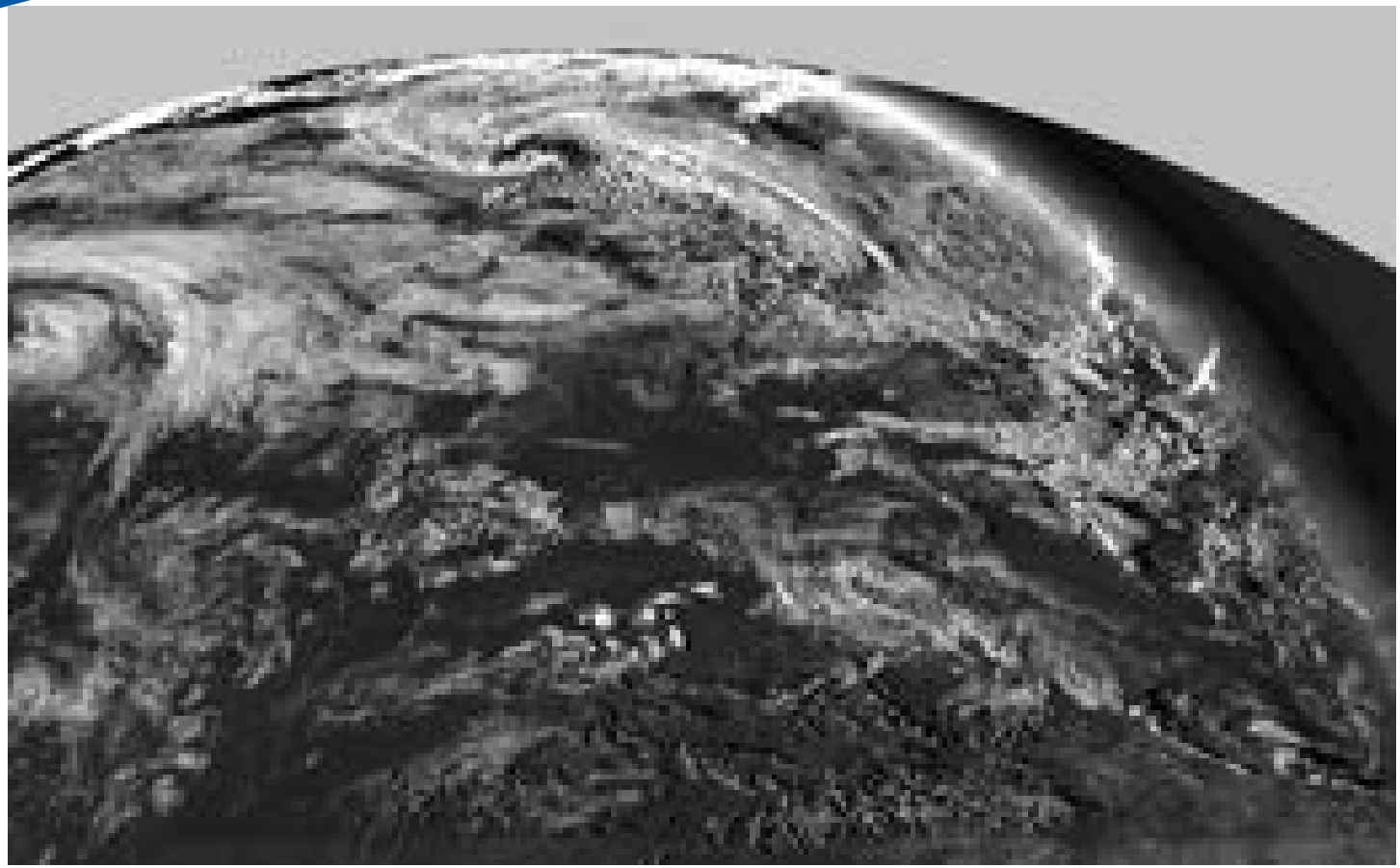


Figure: Cloudindex (date: 13 March, 2005 time: 1545 UTC)

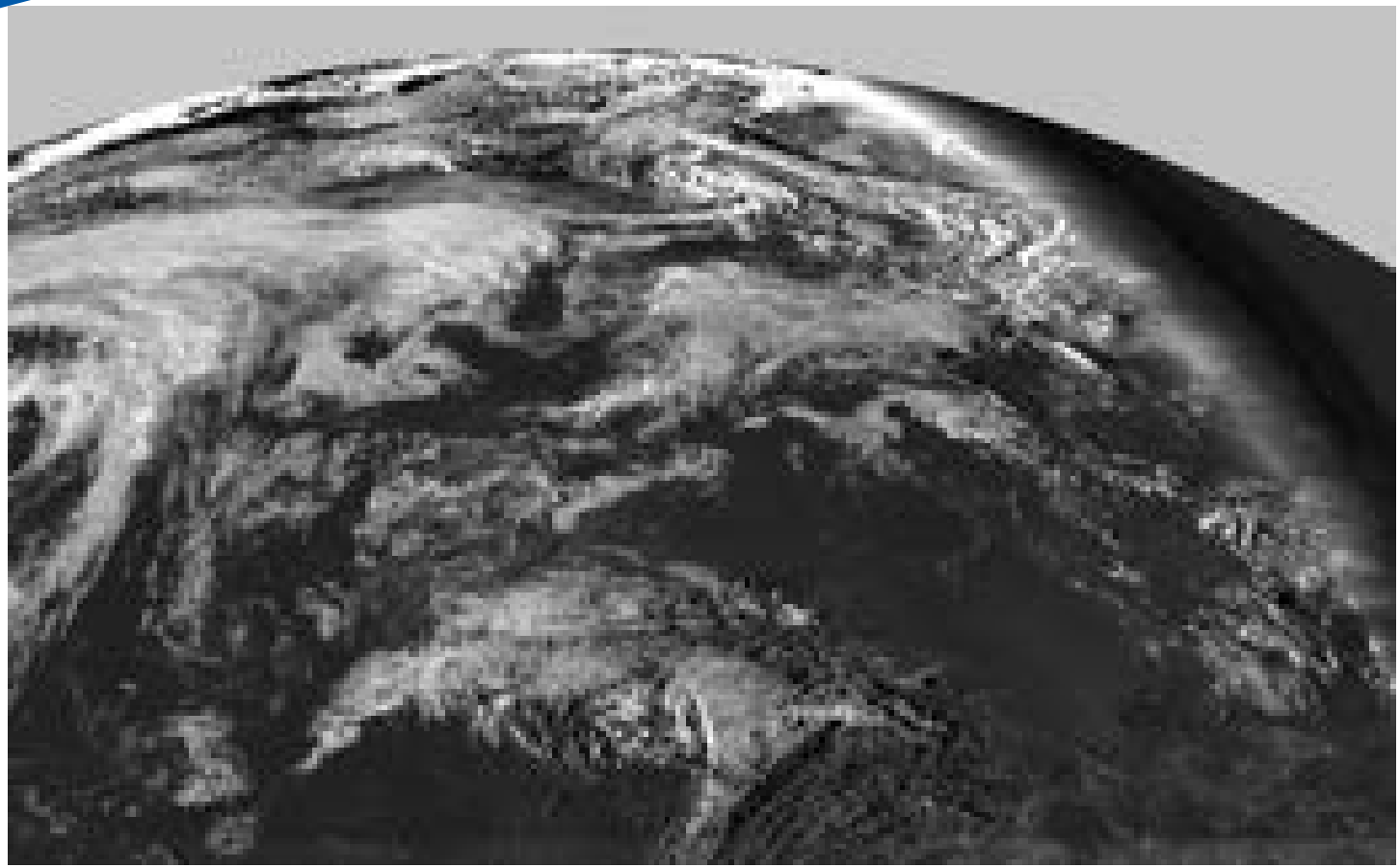


Figure: Cloudindex (date: 14 March, 2005 time: 1545 UTC)

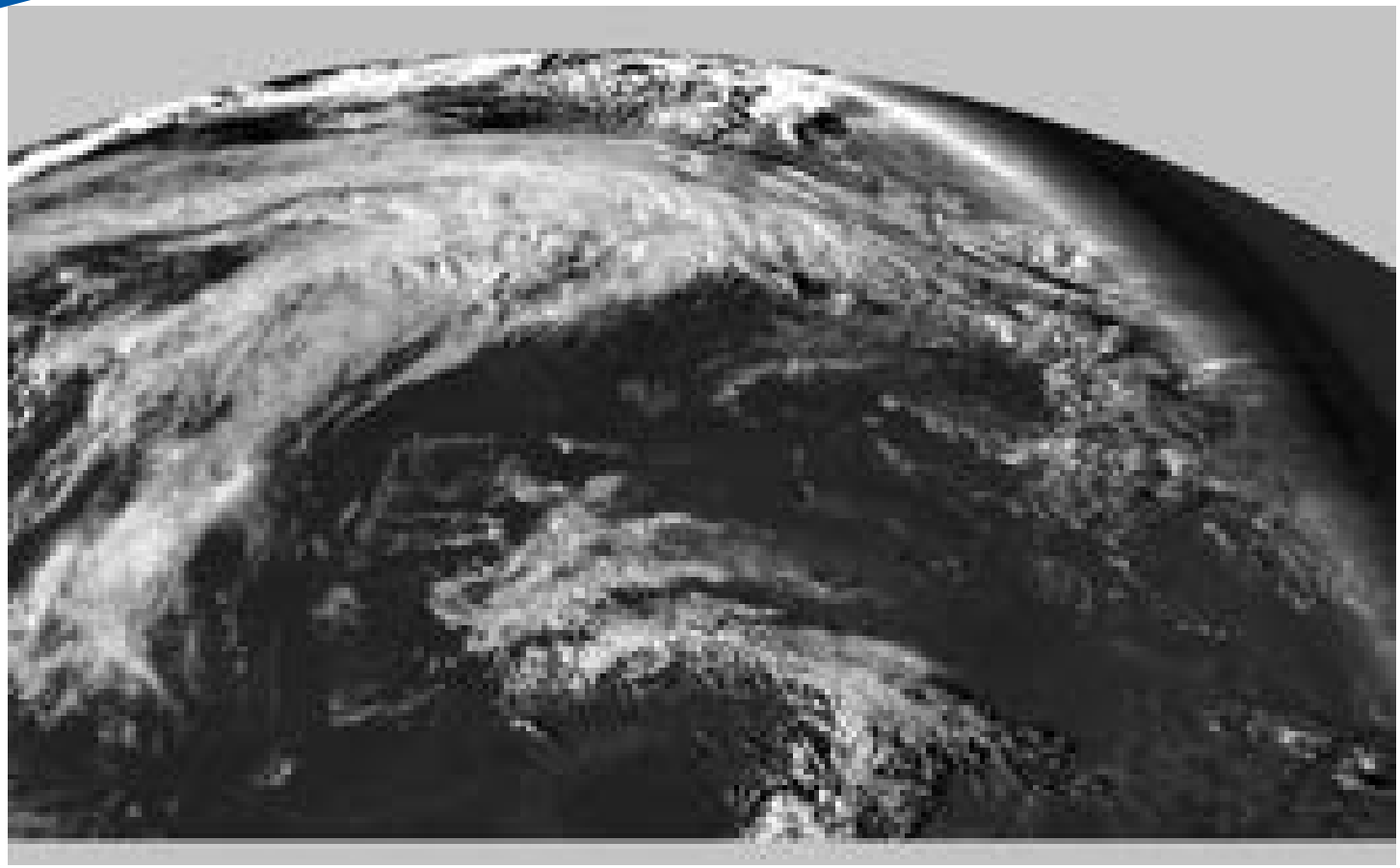


Figure: Cloudindex (date: 15 March, 2005 time: 1545 UTC)

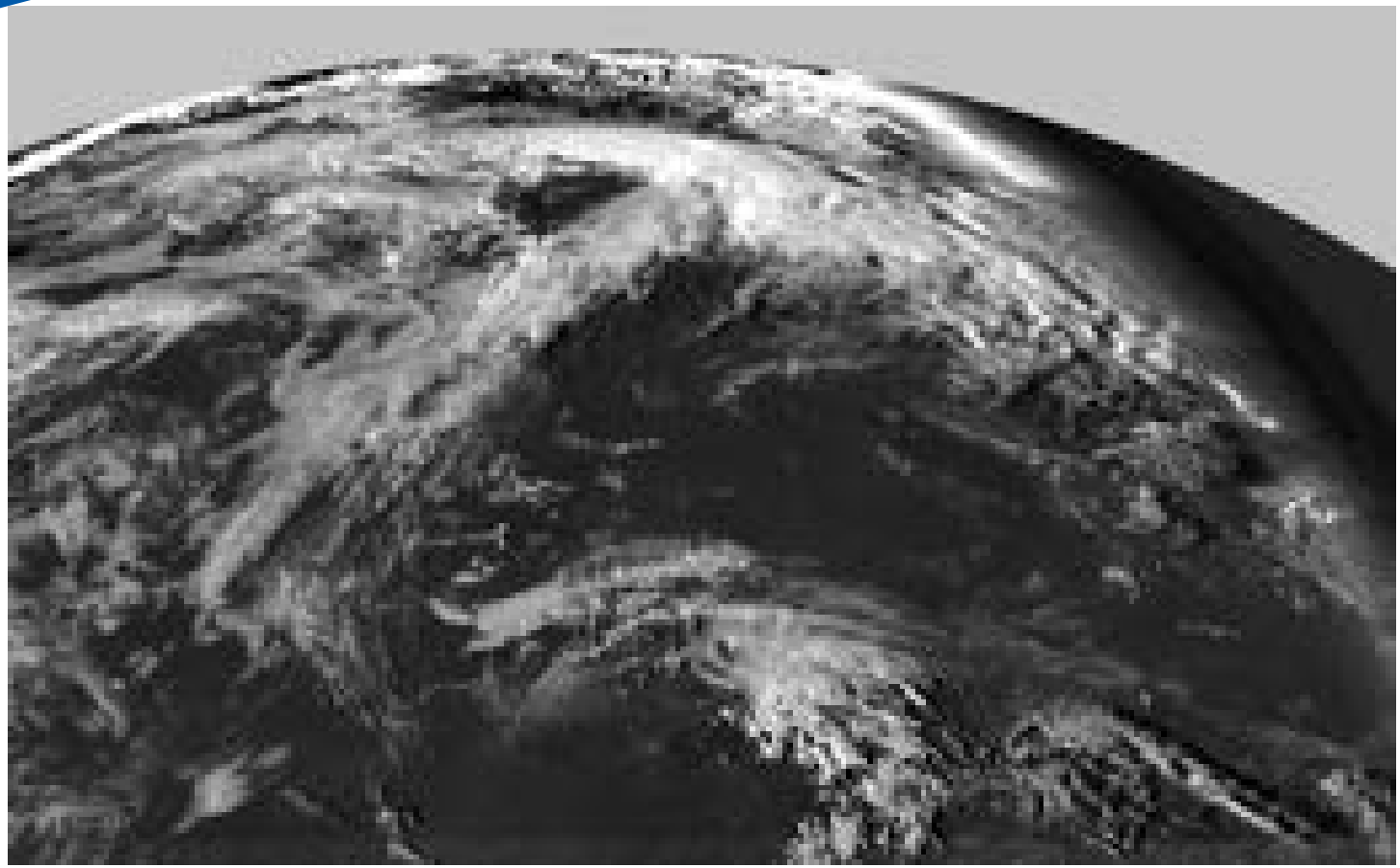


Figure: Cloudindex (date: 16 March, 2005 time: 1545 UTC)

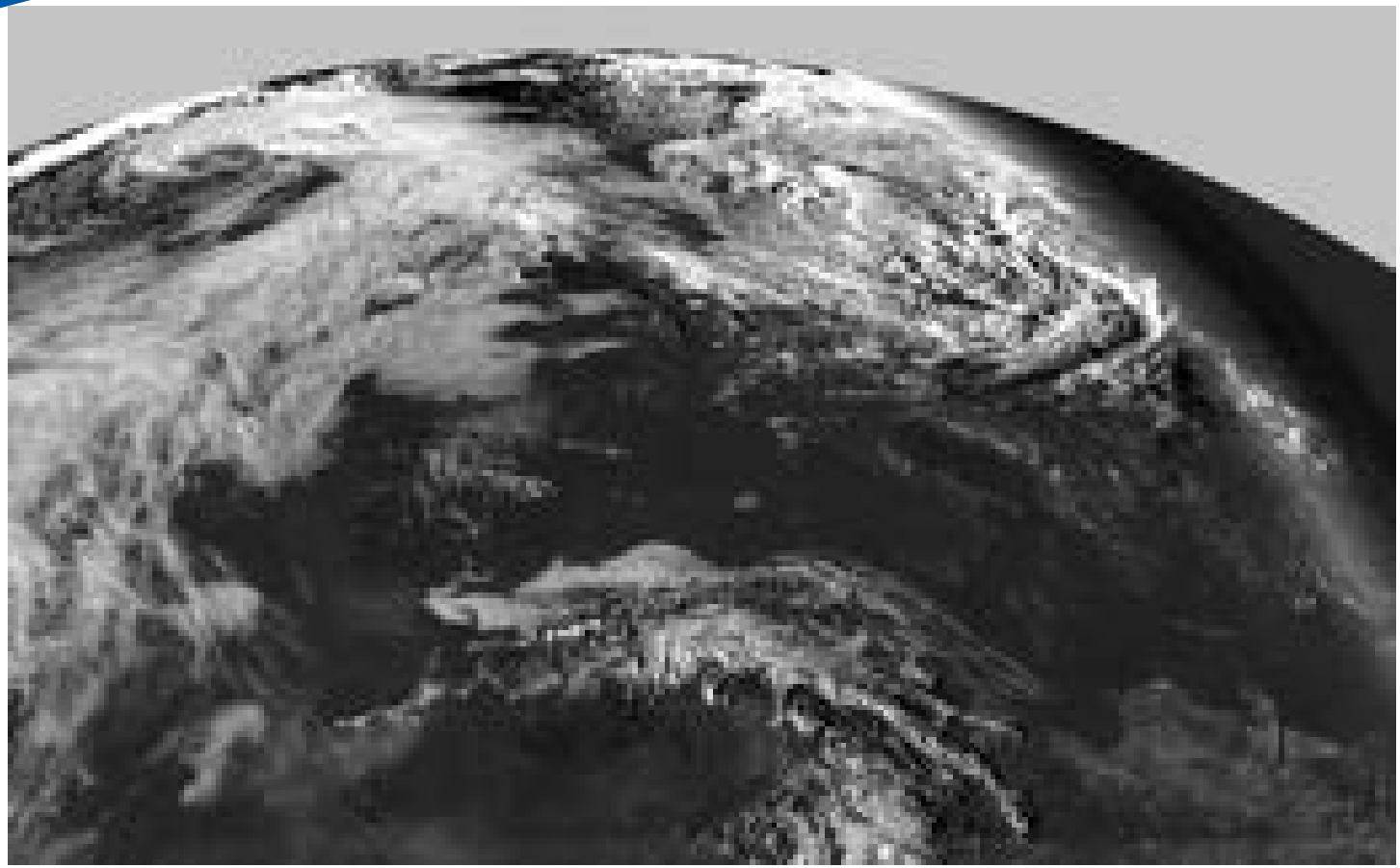


Figure: Cloudindex (date: 17 March, 2005 time: 1545 UTC)

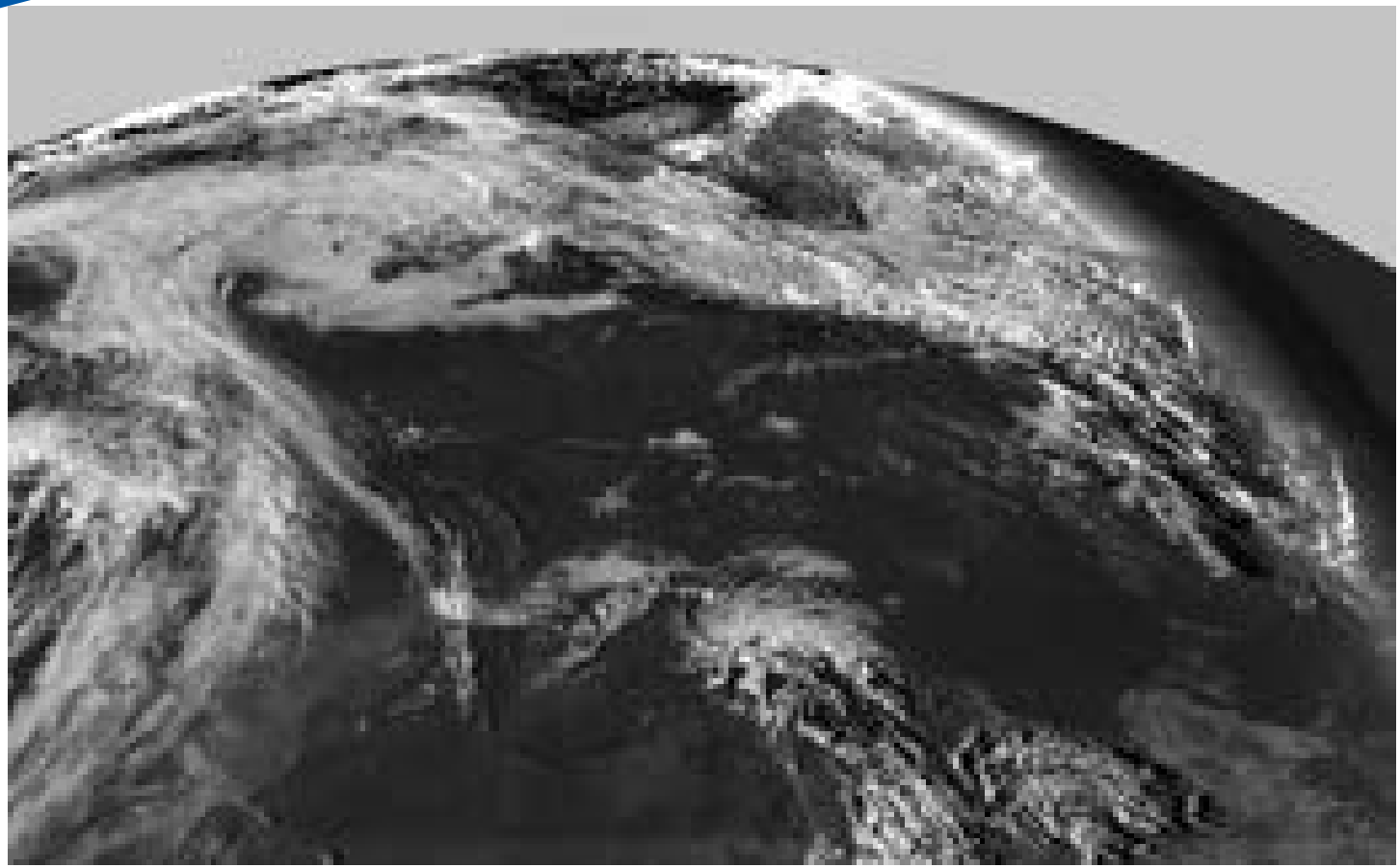


Figure: Cloudindex (date: 18 March, 2005 time: 1545 UTC)

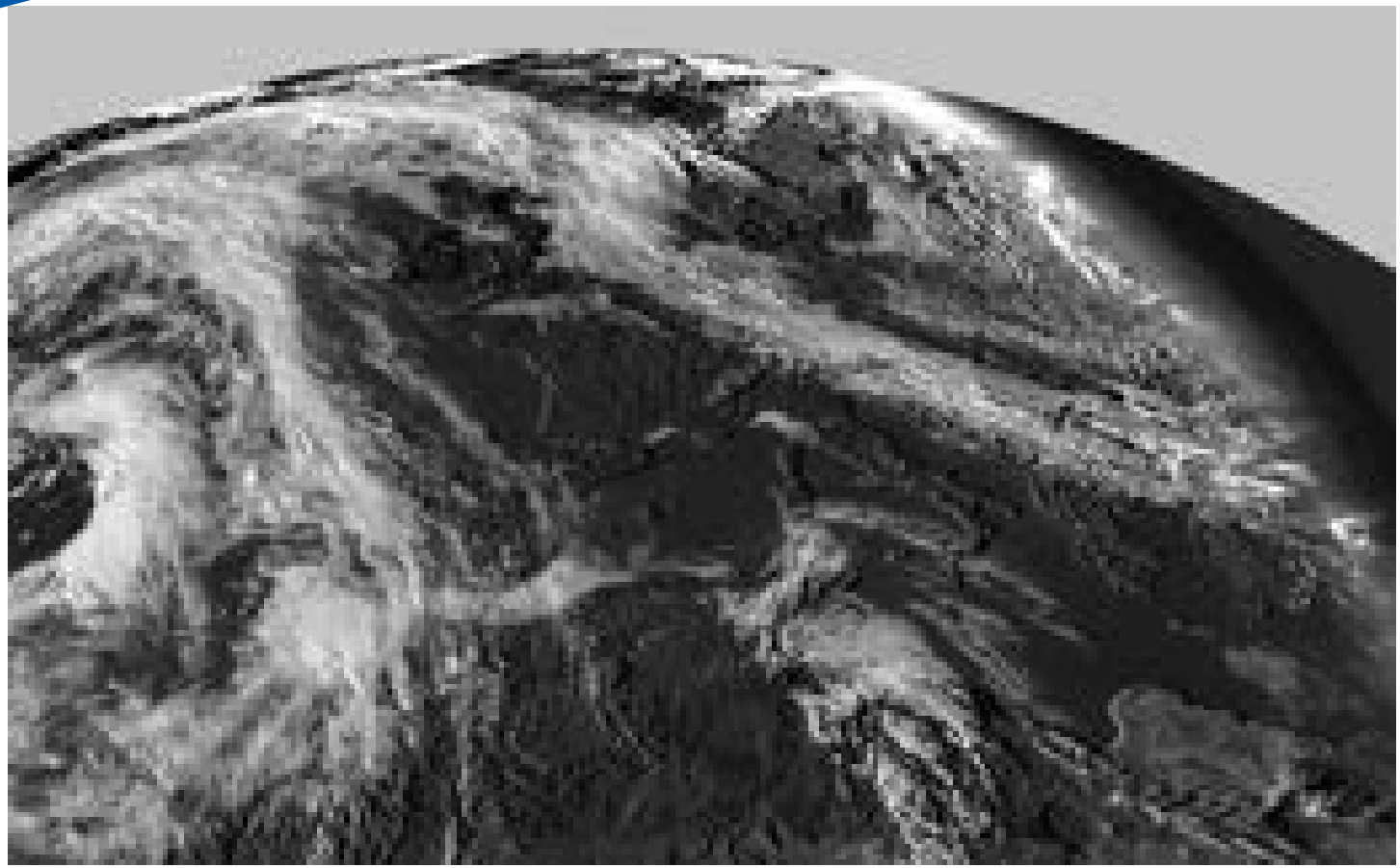


Figure: Cloudindex (date: 19 March, 2005 time: 1545 UTC)

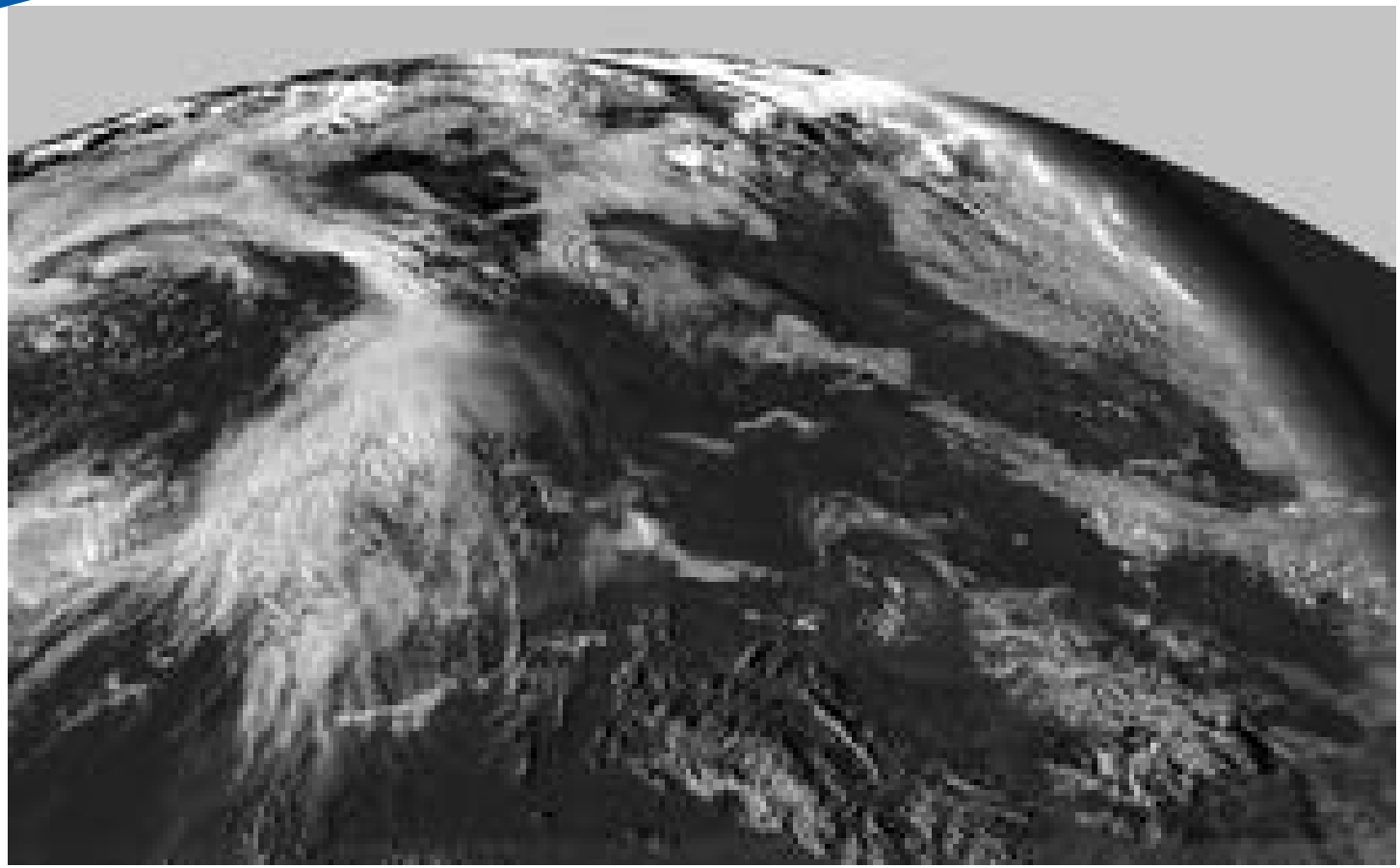


Figure: Cloudindex (date: 20 March, 2005 time: 1545 UTC)

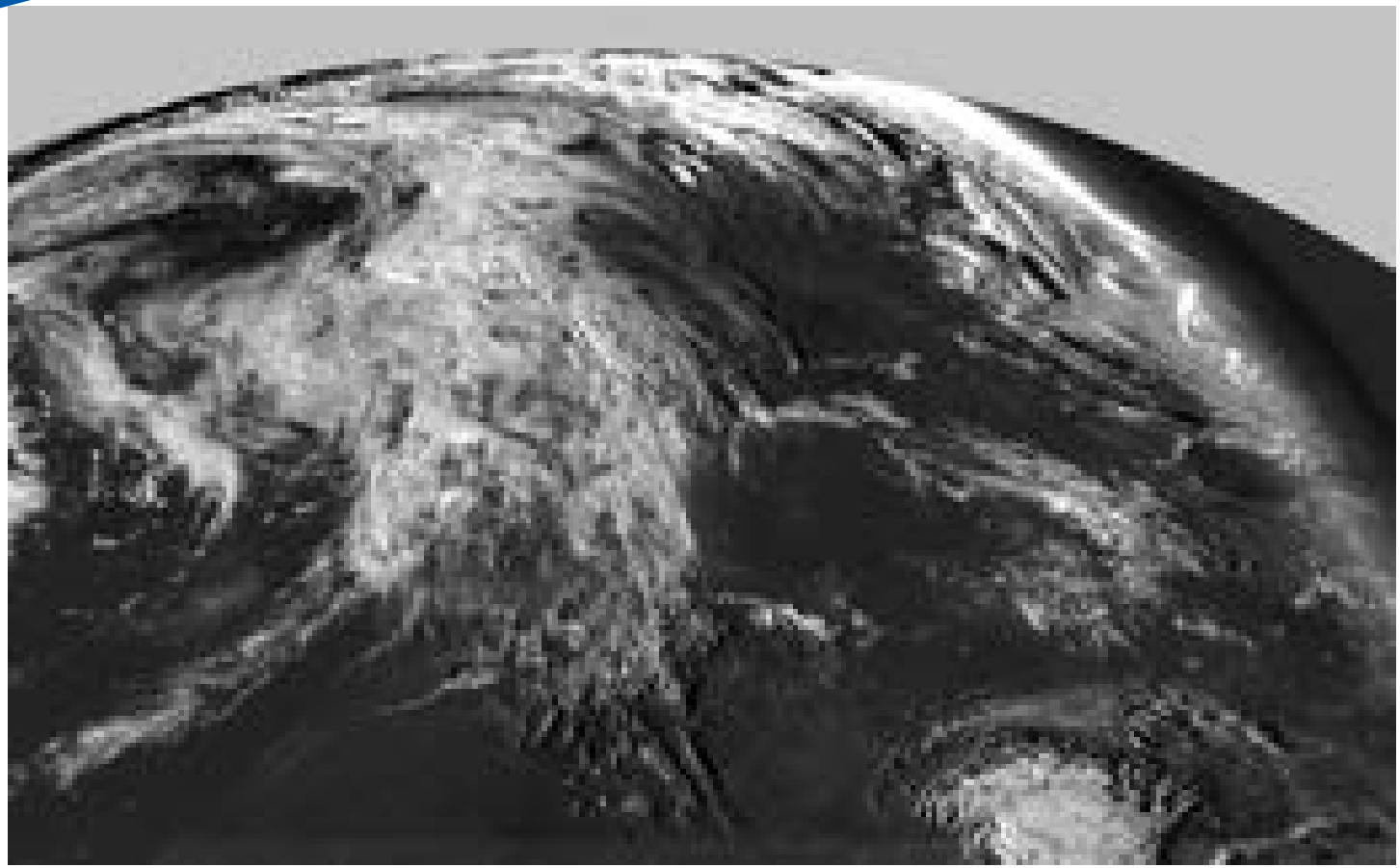


Figure: Cloudindex (date: 21 March, 2005 time: 1545 UTC)

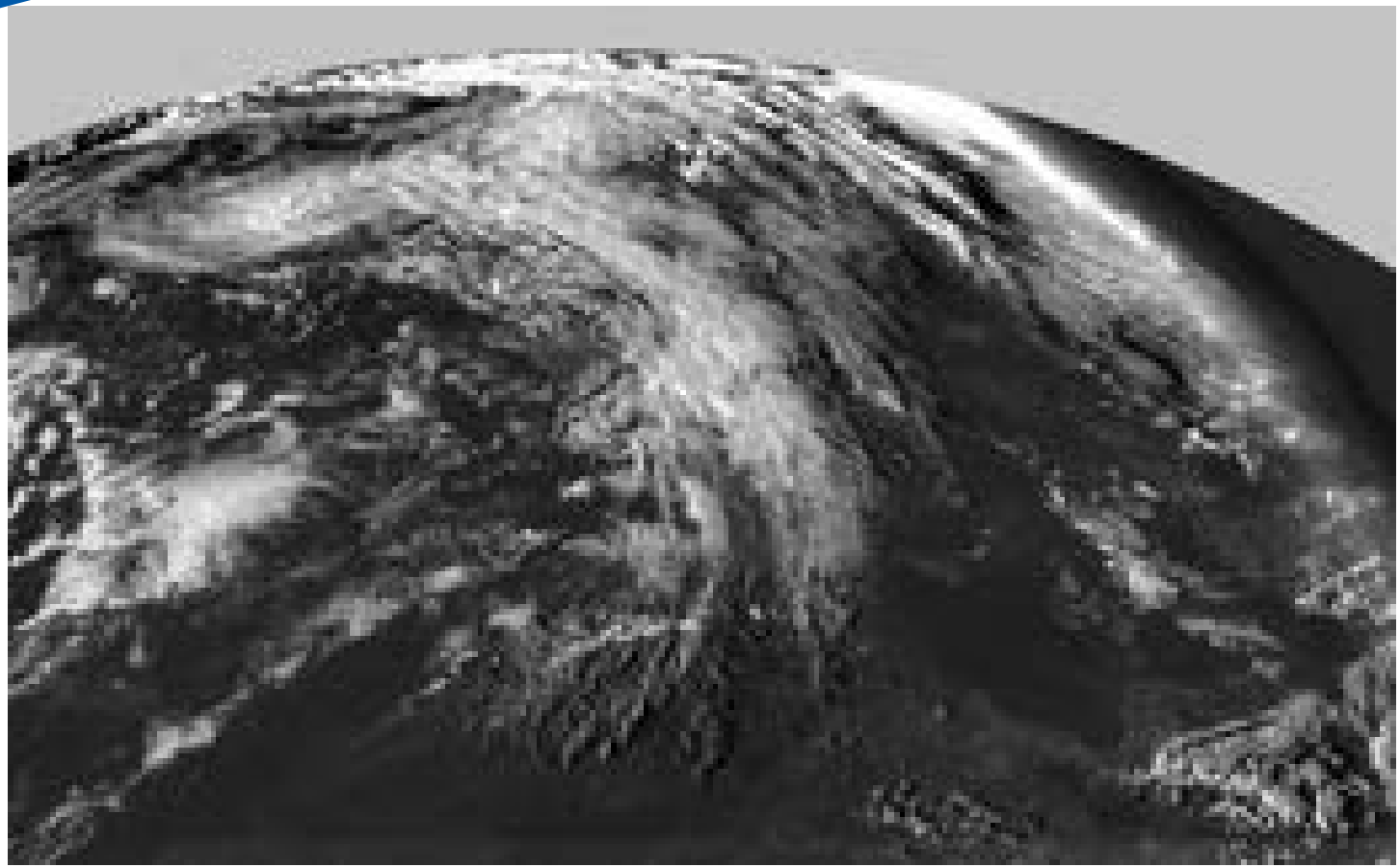


Figure: Cloudindex (date: 22 March, 2005 time: 1545 UTC)

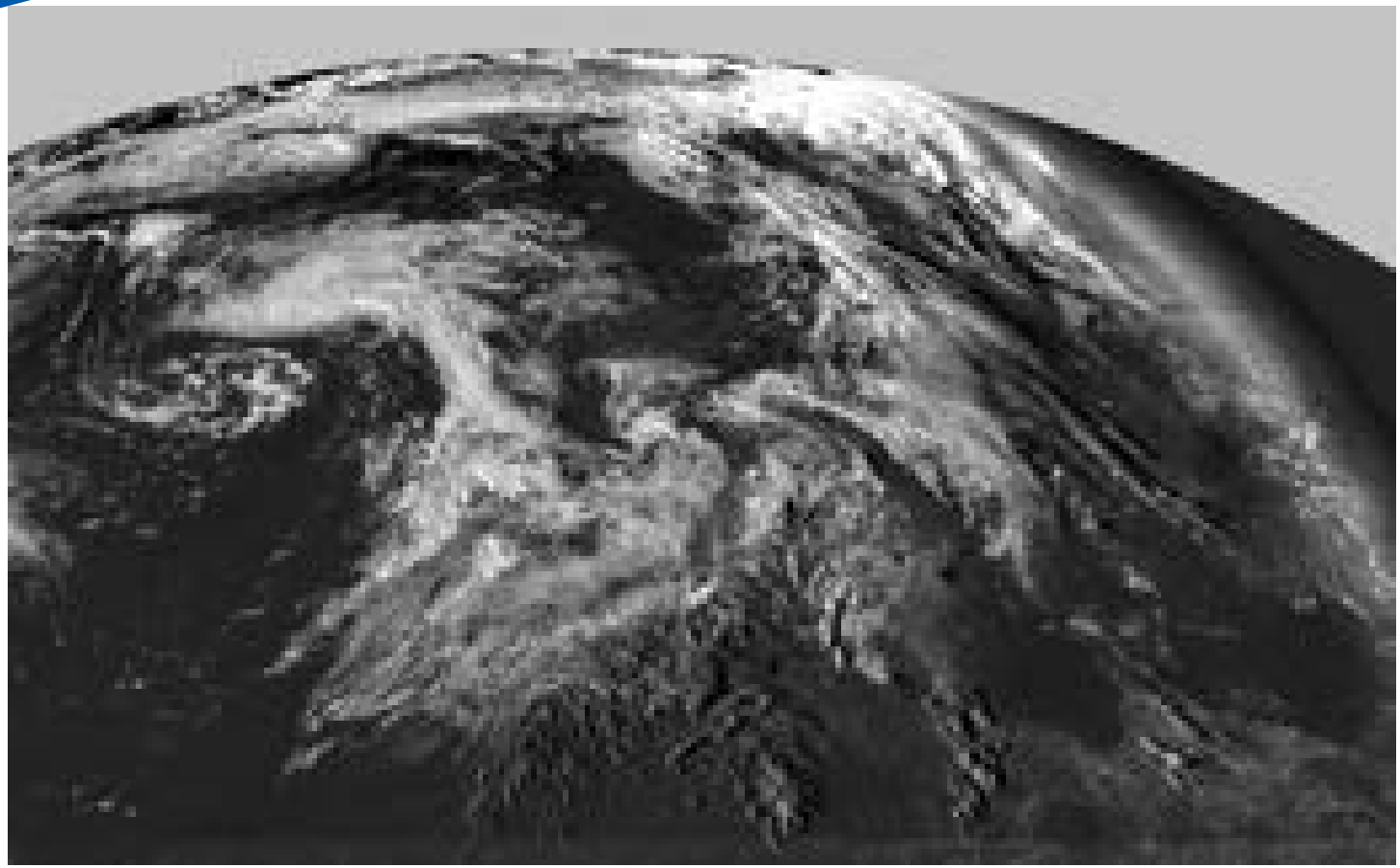


Figure: Cloudindex (date: 23 March, 2005 time: 1545 UTC)

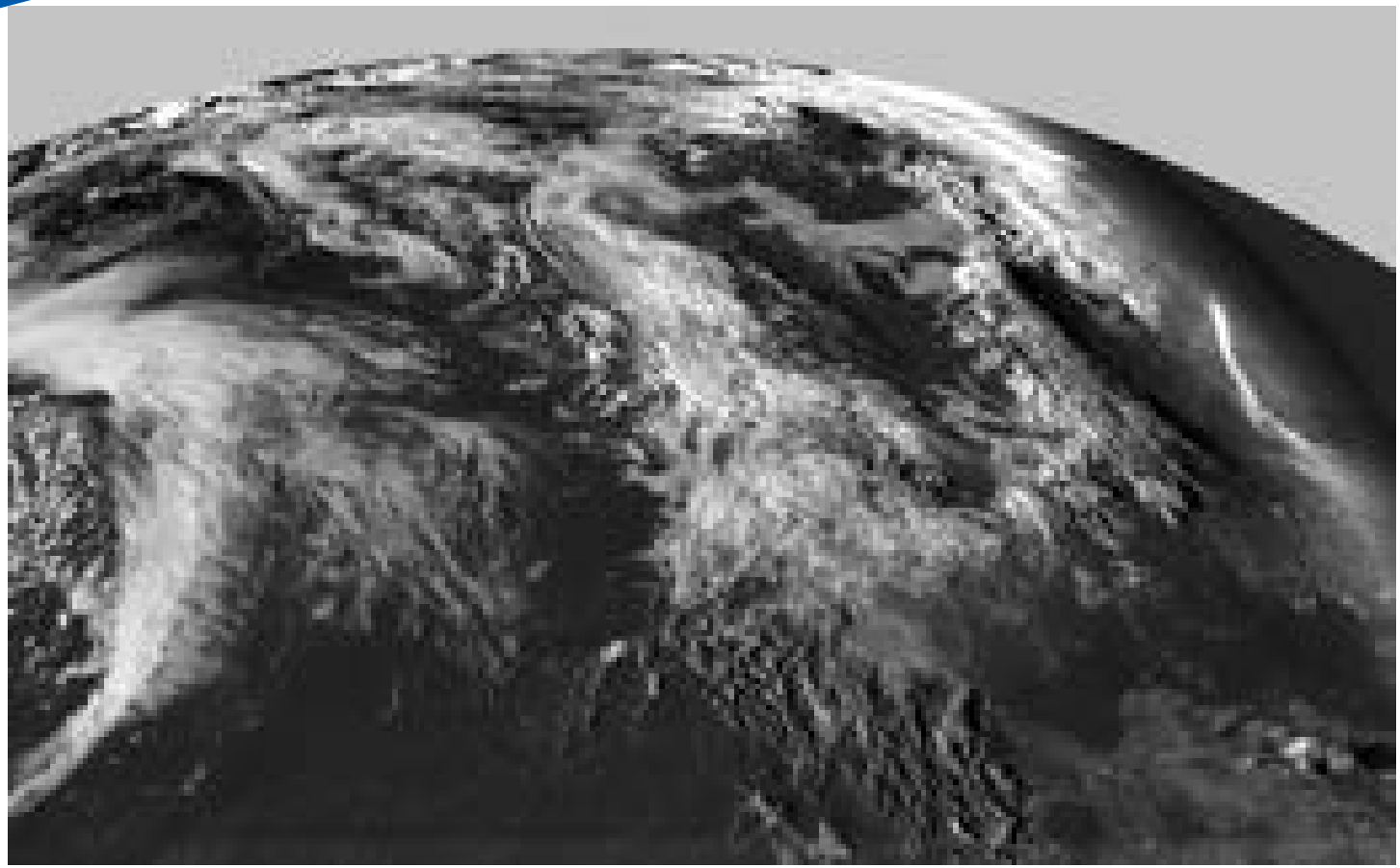


Figure: Cloudindex (date: 24 March, 2005 time: 1545 UTC)

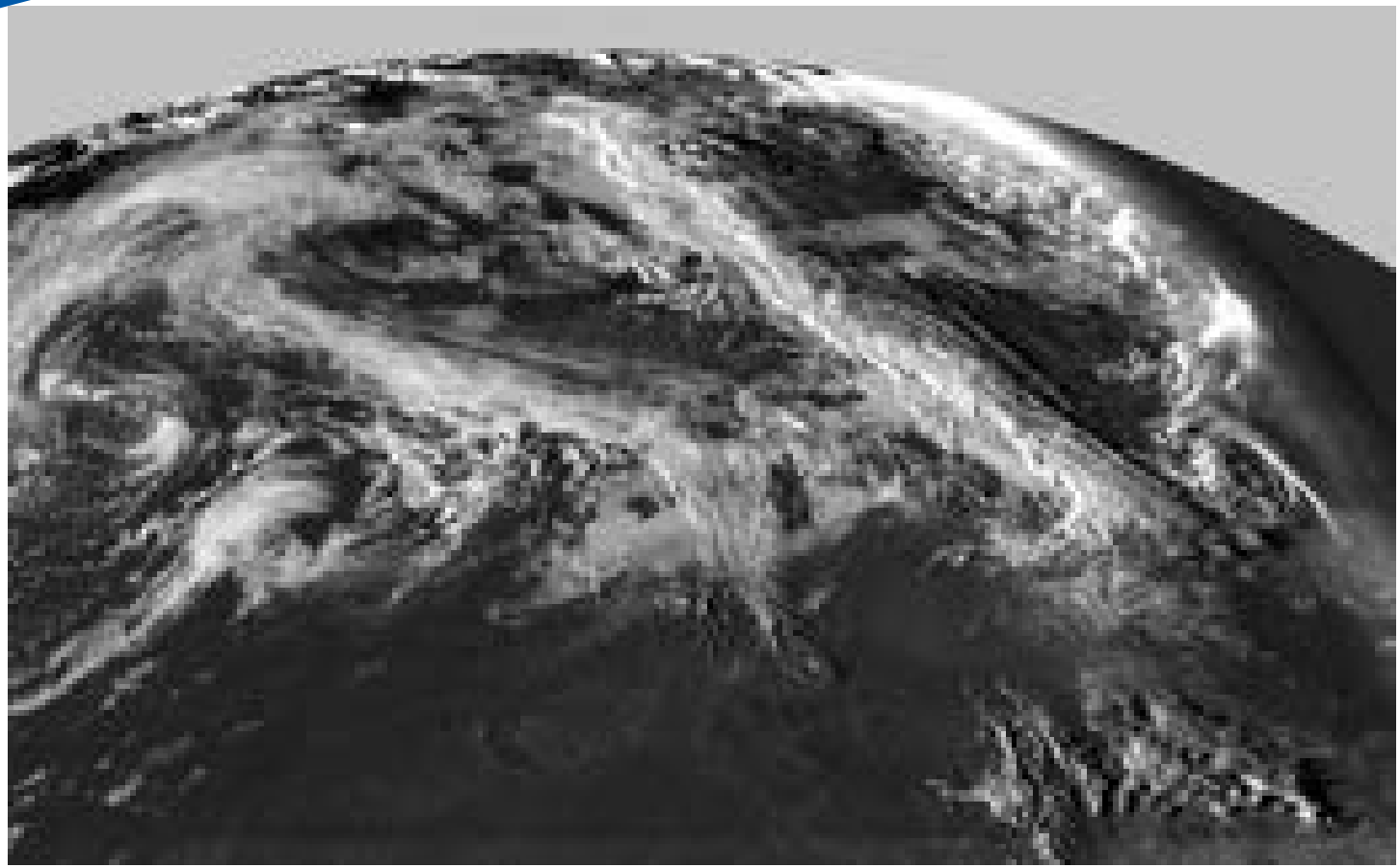


Figure: Cloudindex (date: 25 March, 2005 time: 1545 UTC)

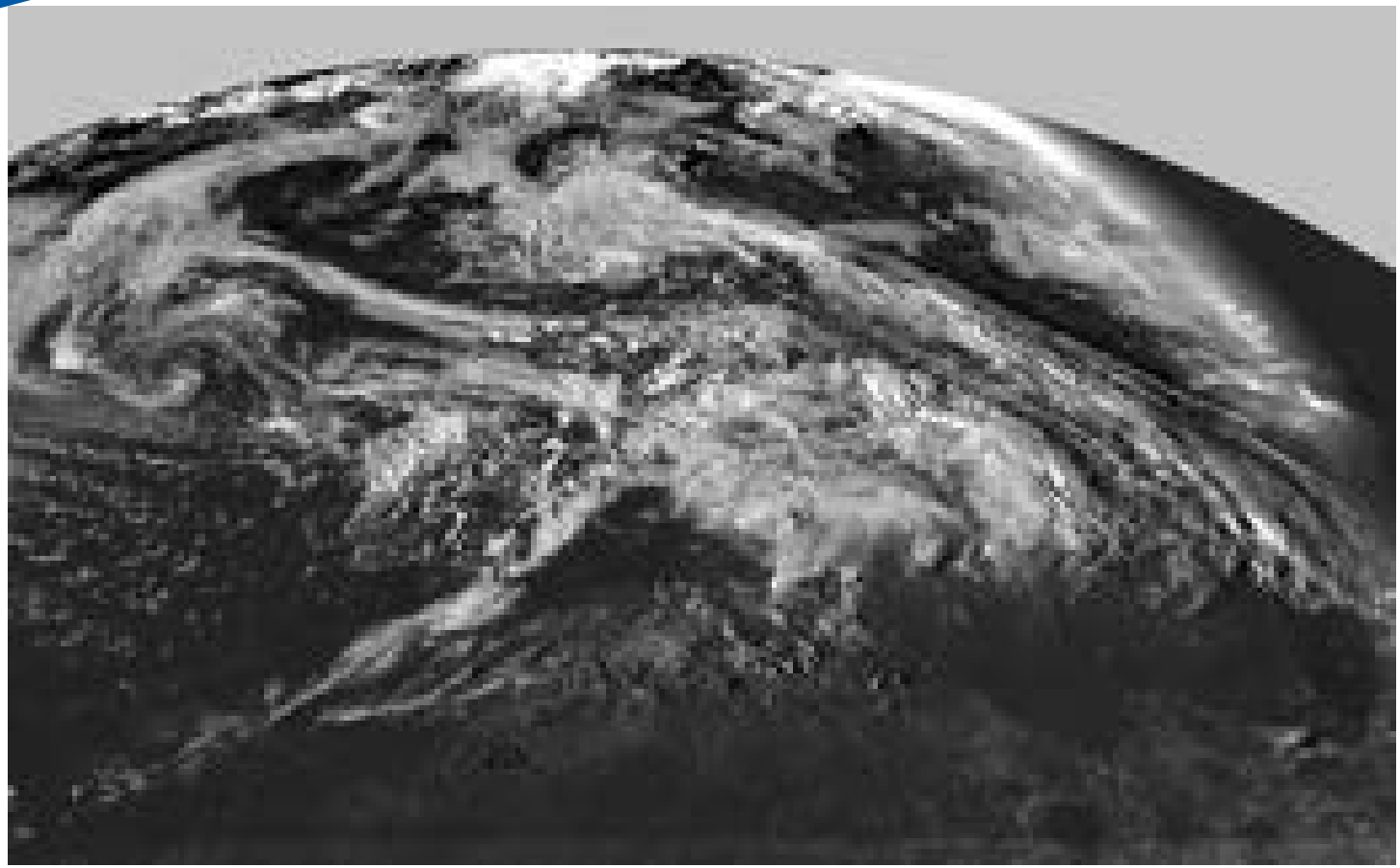


Figure: Cloudindex (date: 26 March, 2005 time: 1545 UTC)

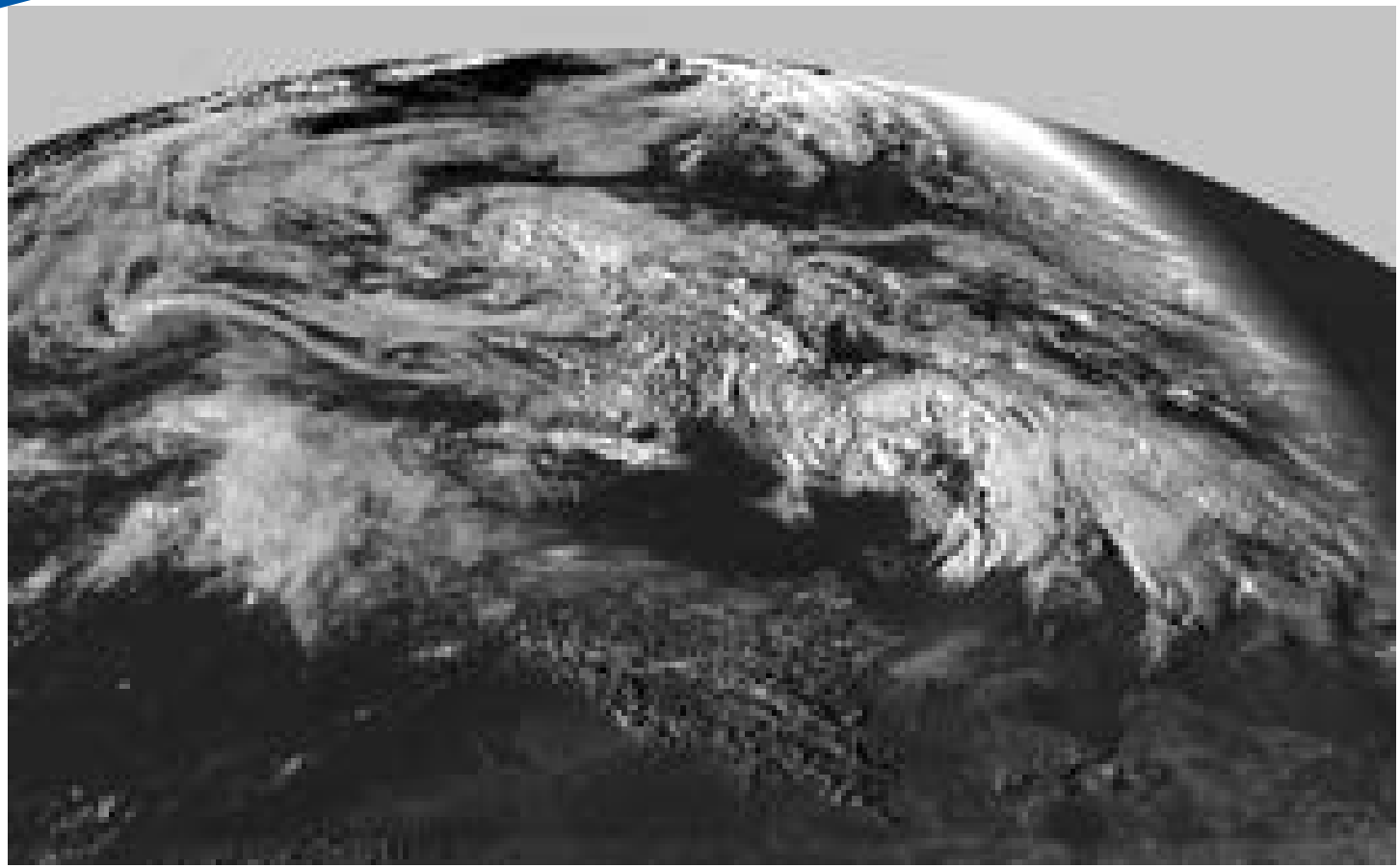


Figure: Cloudindex (date: 27 March, 2005 time: 1545 UTC)

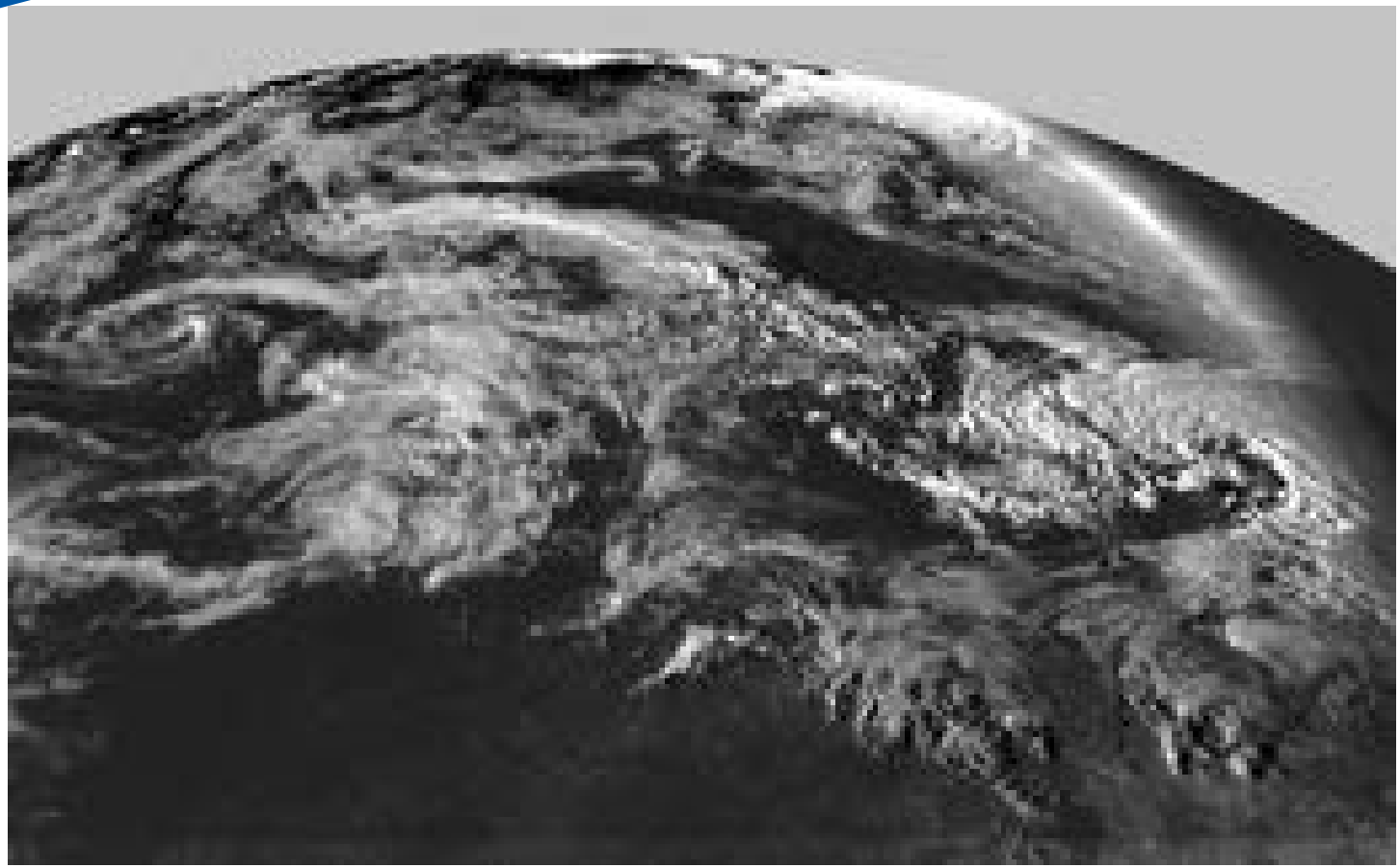


Figure: Cloudindex (date: 28 March, 2005 time: 1545 UTC)

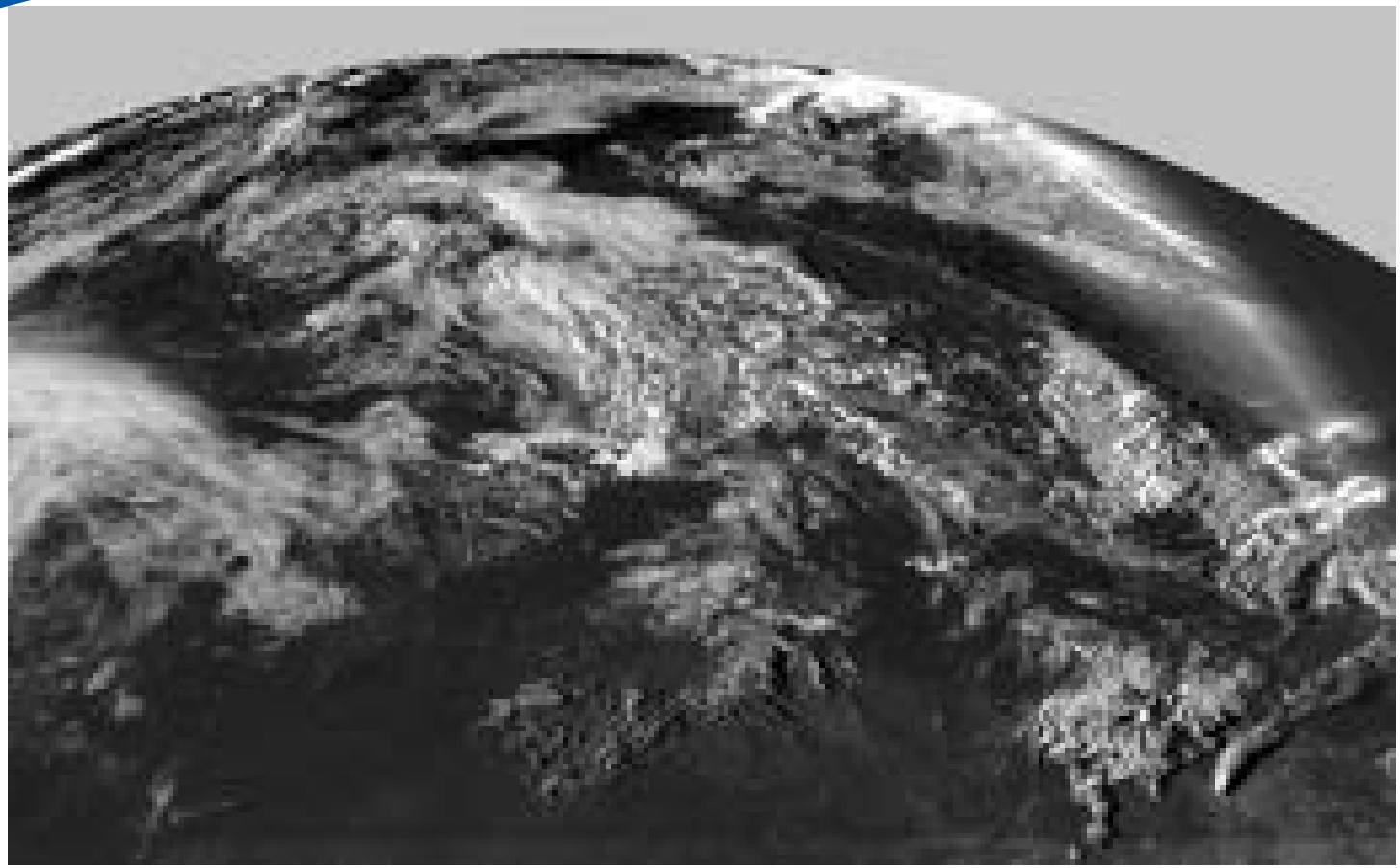


Figure: Cloudindex (date: 29 March, 2005 time: 1545 UTC)

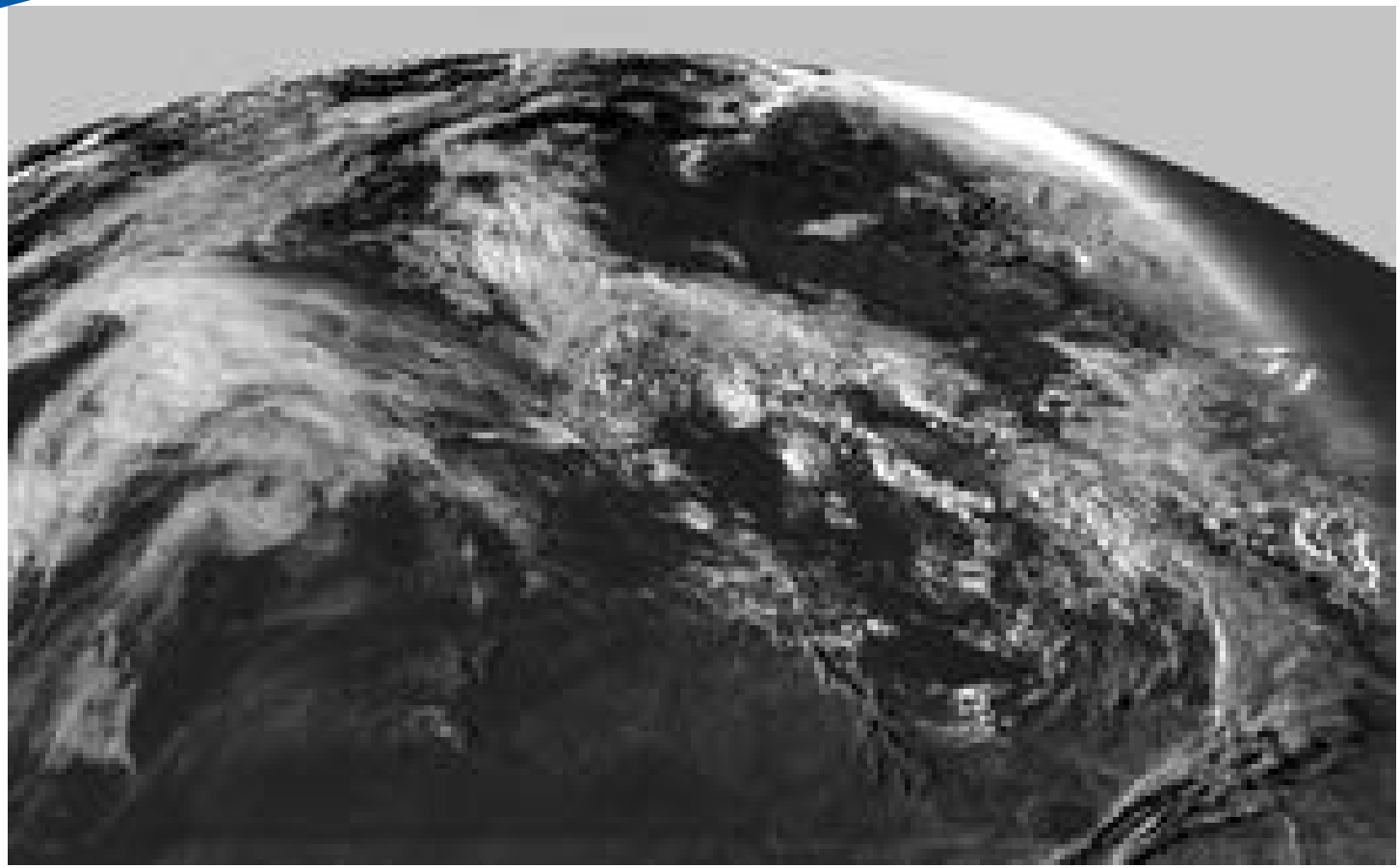


Figure: Cloudindex (date: 30 March, 2005 time: 1545 UTC)

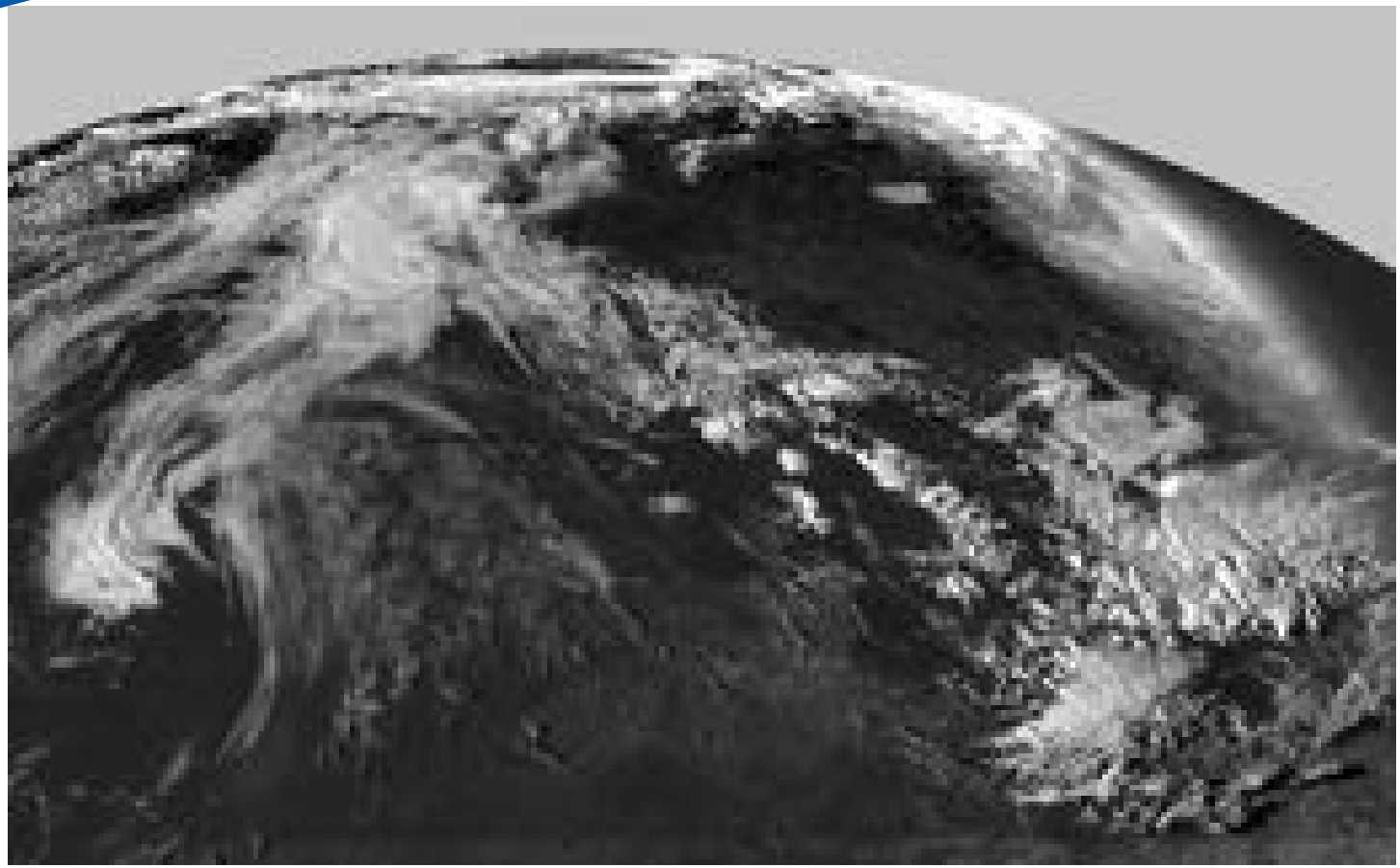


Figure: Cloudindex (date: 31 March, 2005 time: 1545 UTC)

Identifying the problems

Problem 1: Defective images

- Images with strange artifacts
  - data loss at specific image segment
  - data loss along image pixels
  - problem in one raw image may get transferred to all days of month
  - recurring strange patterns in images
- Issues with image headers
- Corrupted images can be few pixels shifted
- Complete day missing due to technical reasons

Recurring pattern

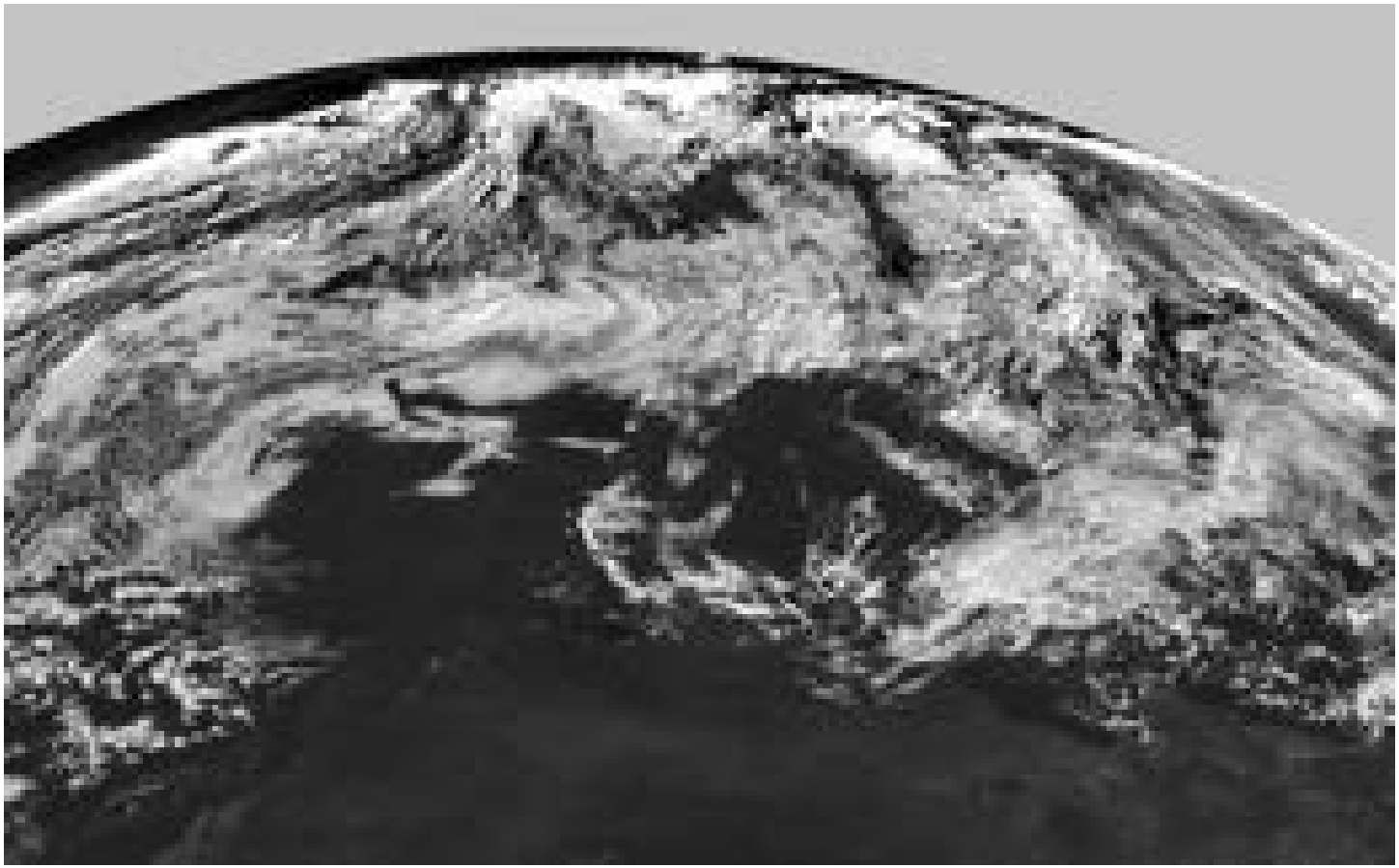


Figure: Cloudindex (date: 02 February, 2005 time: 1015 UTC)

Recurring pattern

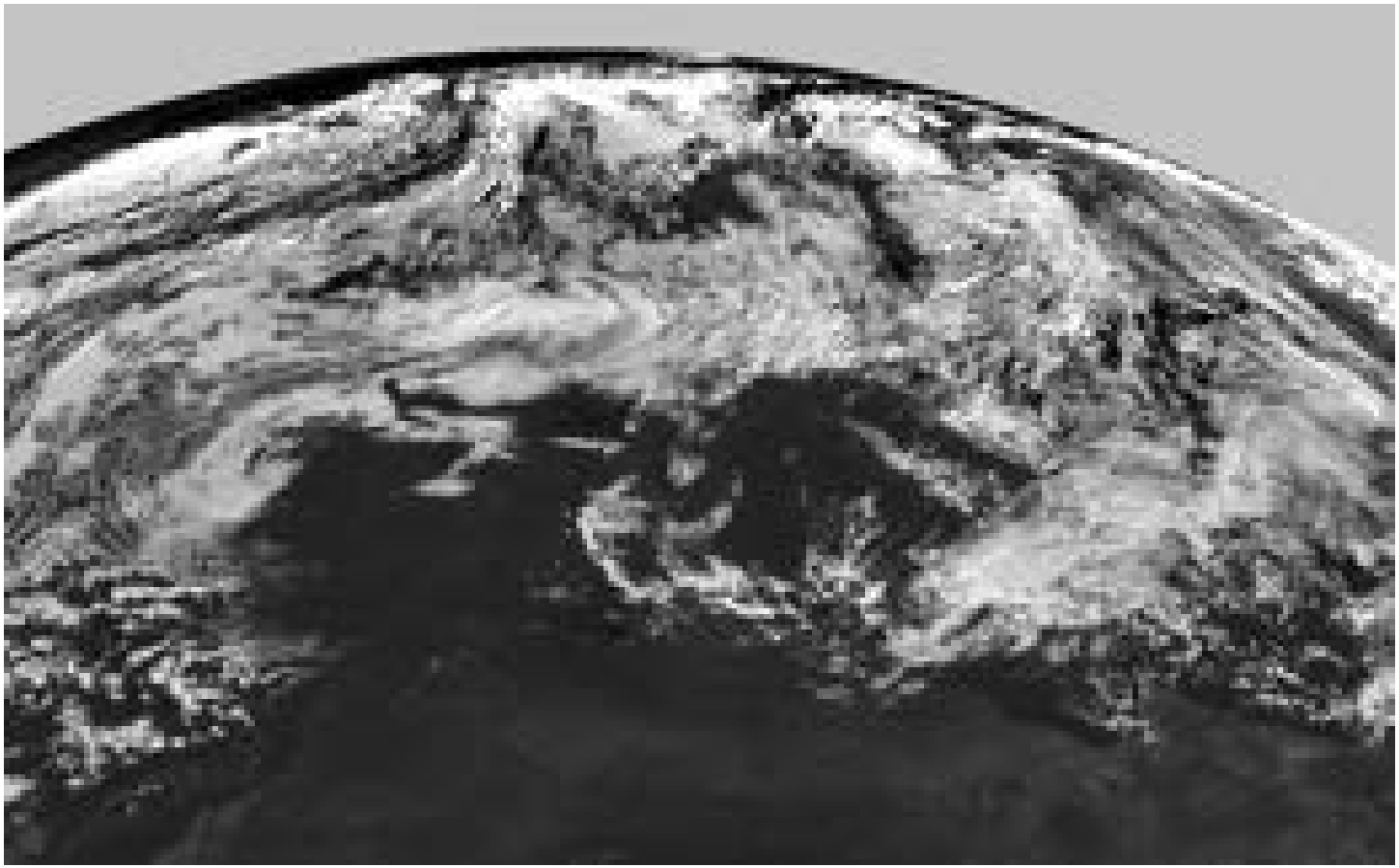


Figure: Cloudindex (date: 02 February, 2005 time: 1030 UTC)

Recurring pattern

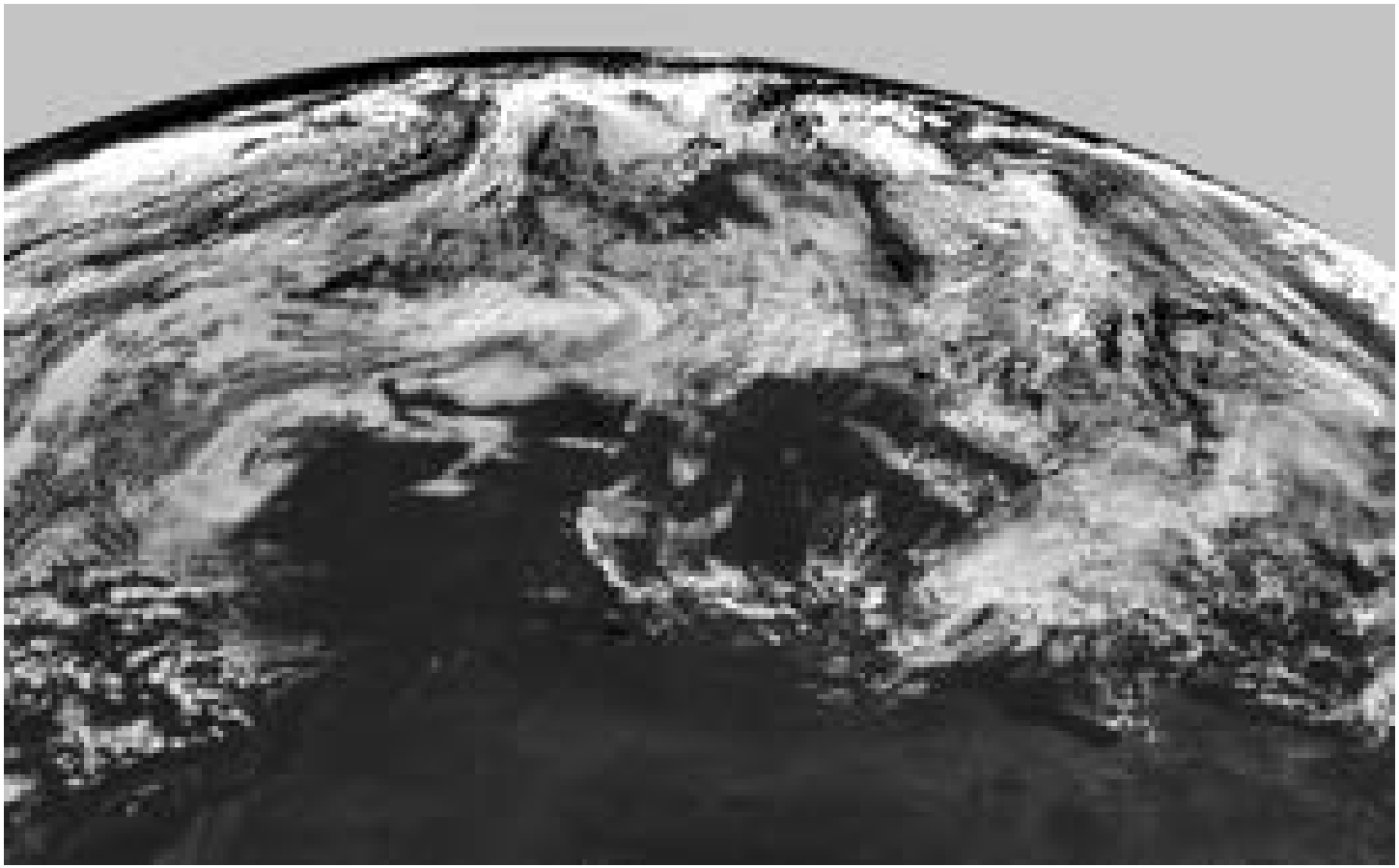


Figure: Cloudindex (date: 02 February, 2005 time: 1045 UTC)

Recurring pattern

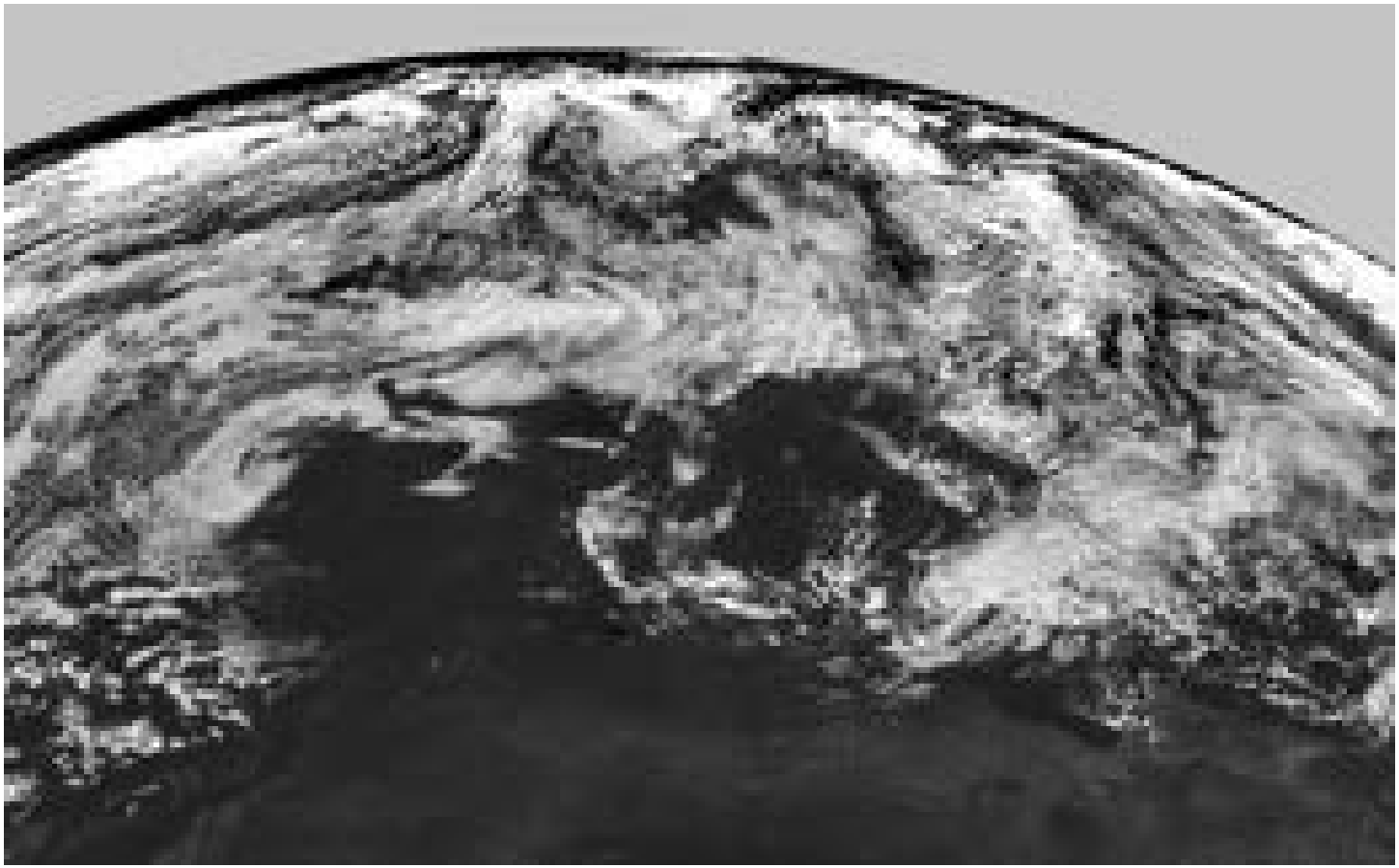


Figure: Cloudindex (date: 02 February, 2005 time: 1100 UTC)

Recurring pattern

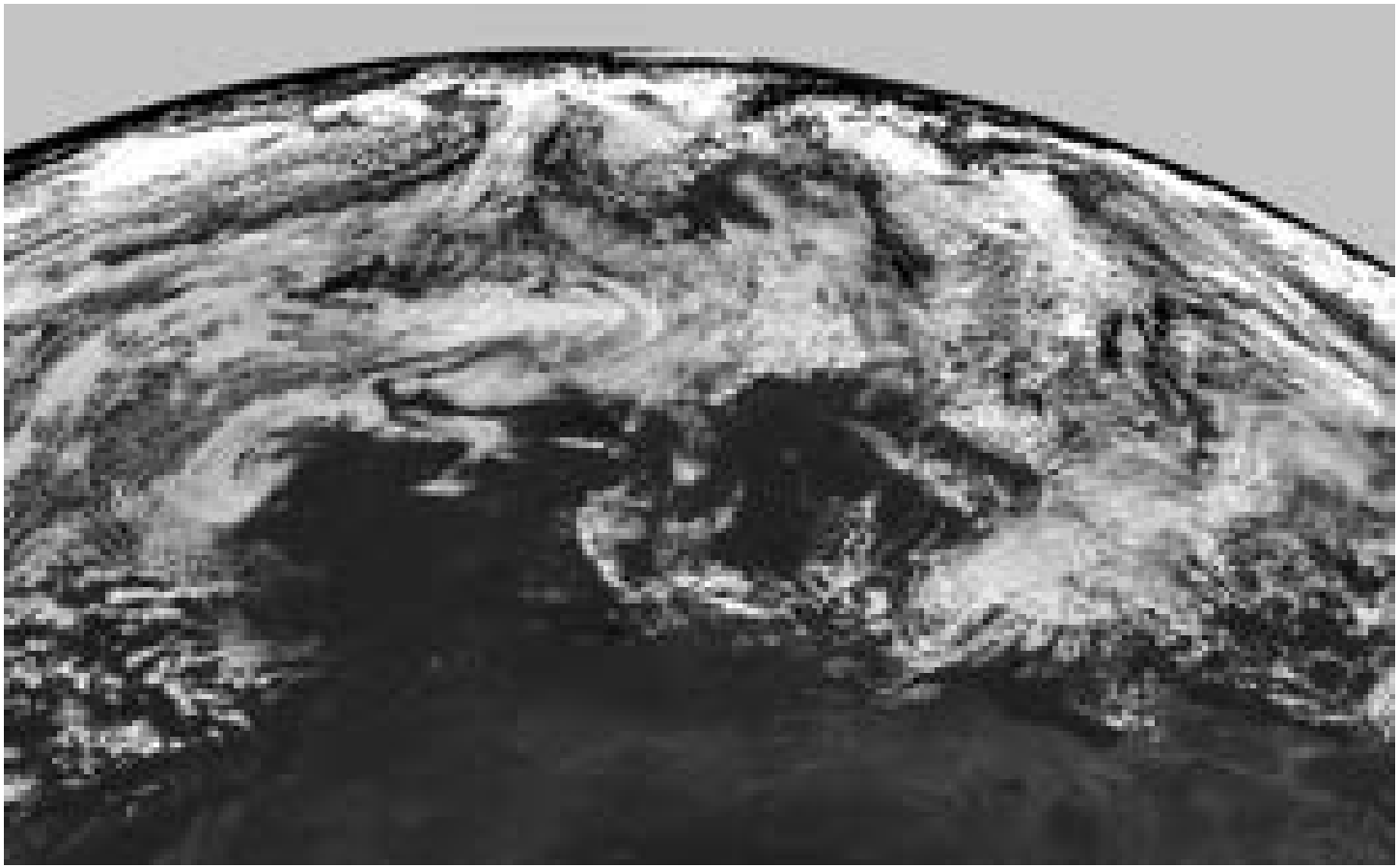


Figure: Cloudindex (date: 02 February, 2005 time: 1115 UTC)

Recurring pattern

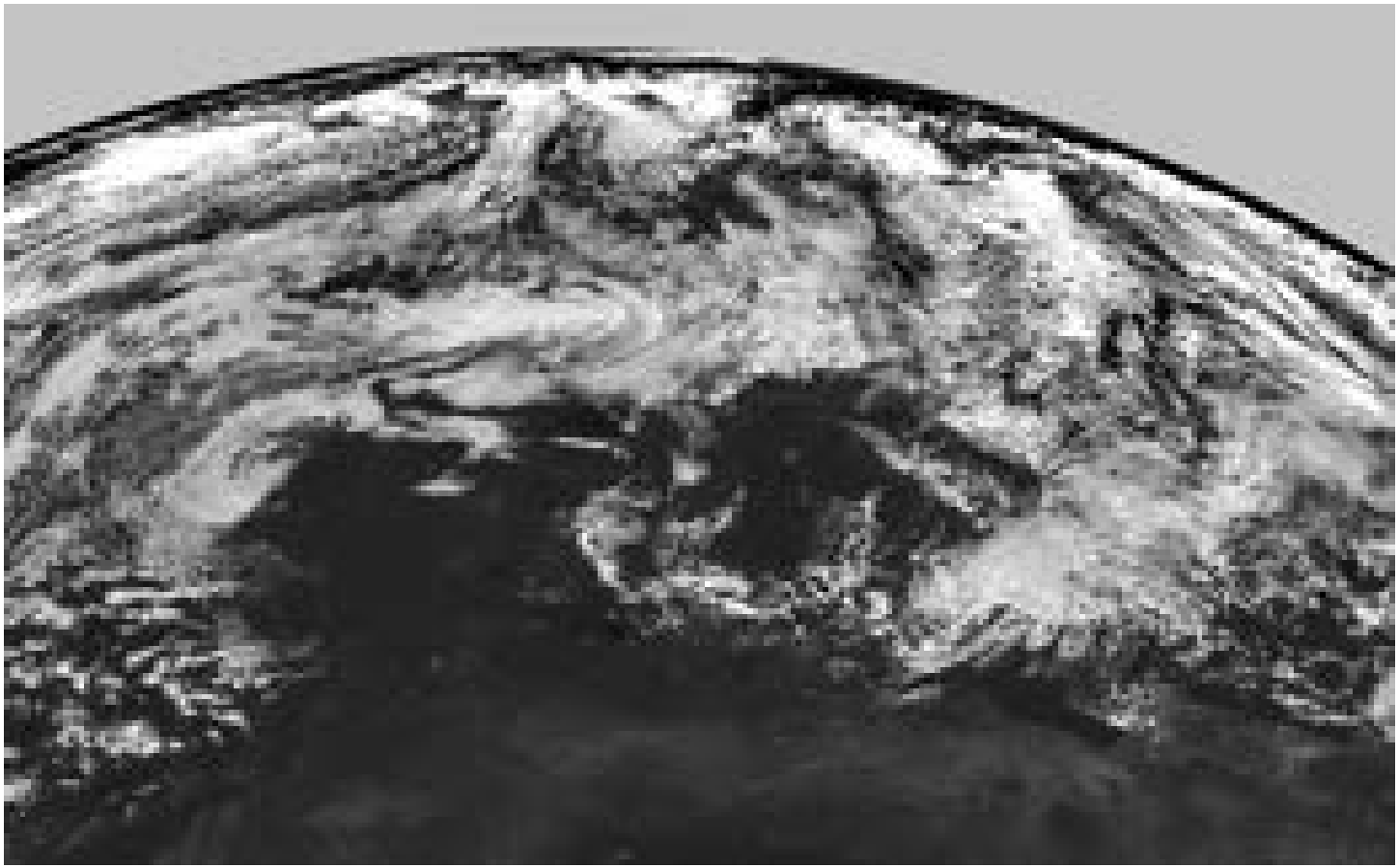


Figure: Cloudindex (date: 02 February, 2005 time: 1130 UTC)

Recurring pattern

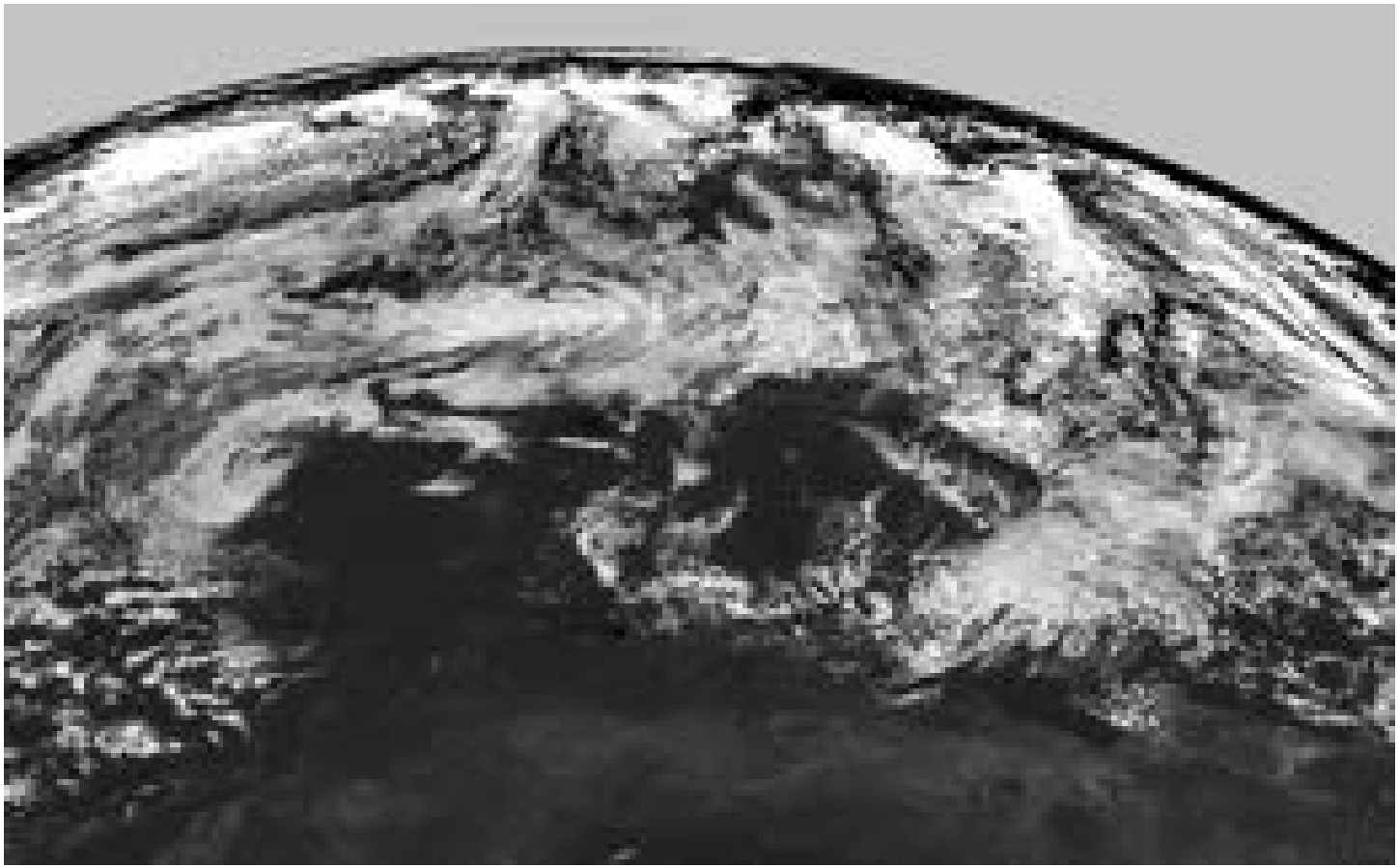


Figure: Cloudindex (date: 02 February, 2005 time: 1145 UTC)

Recurring pattern

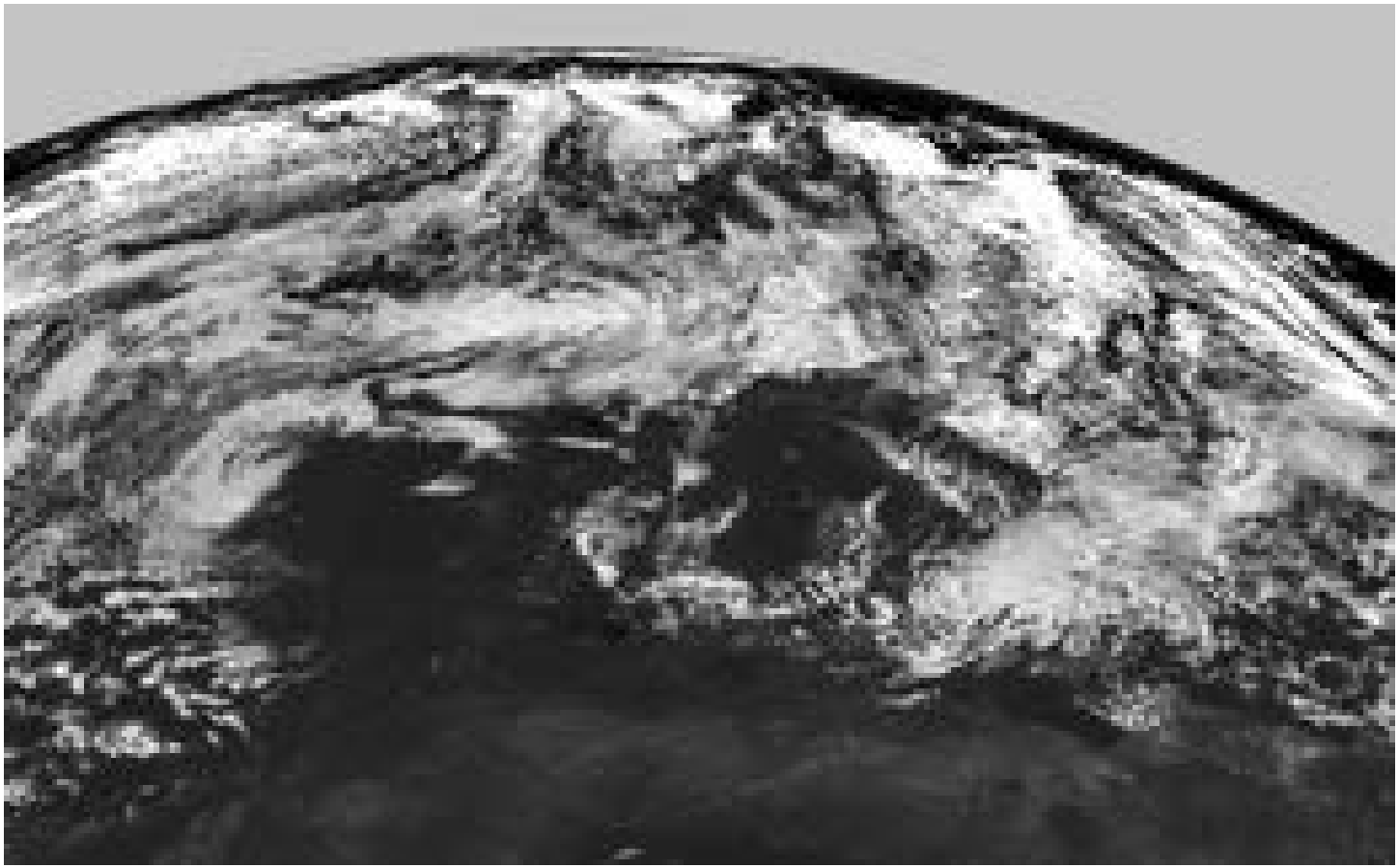


Figure: Cloudindex (date: 02 February, 2005 time: 1200 UTC)

Recurring pattern

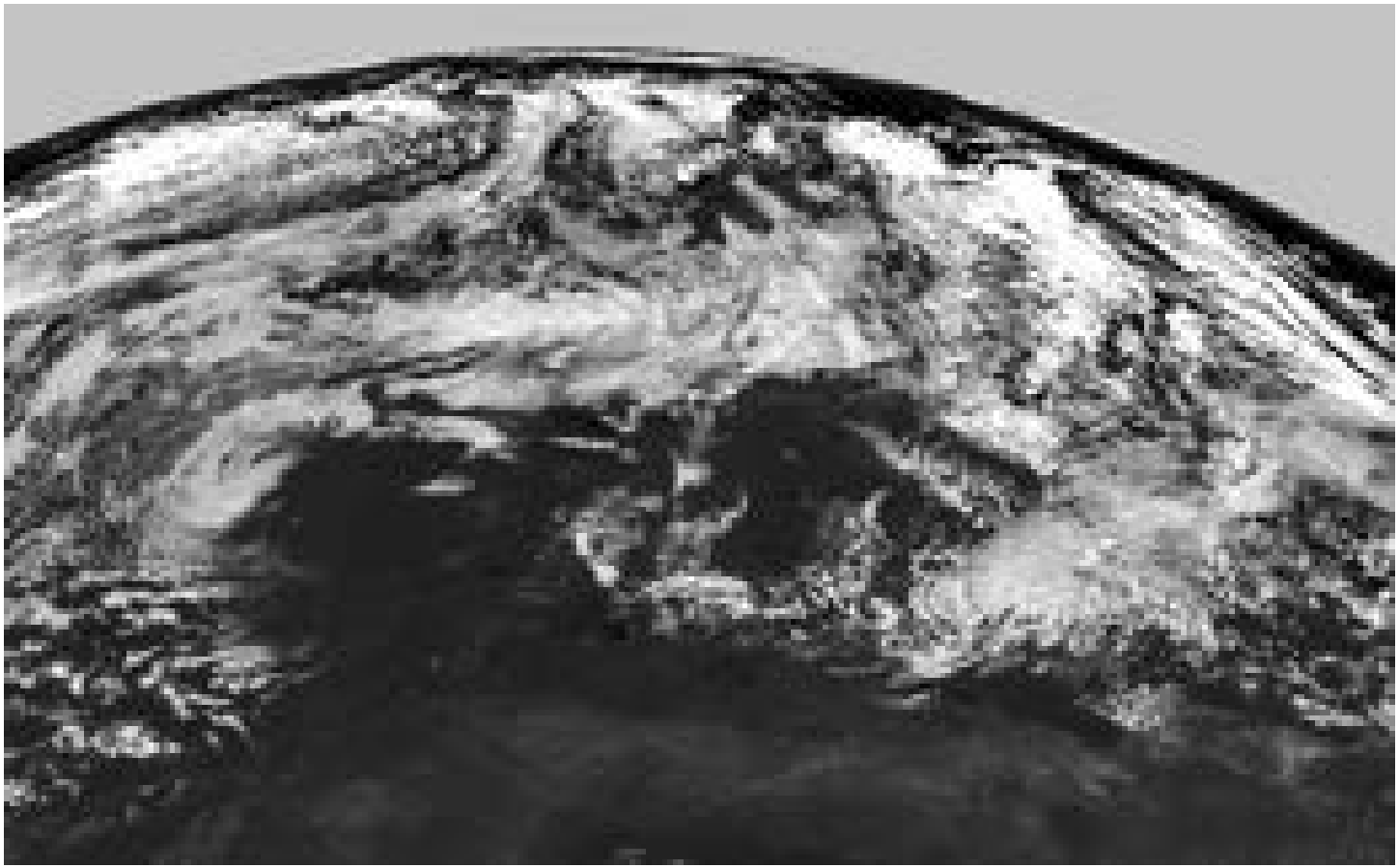


Figure: Cloudindex (date: 02 February, 2005 time: 1215 UTC)

Recurring pattern

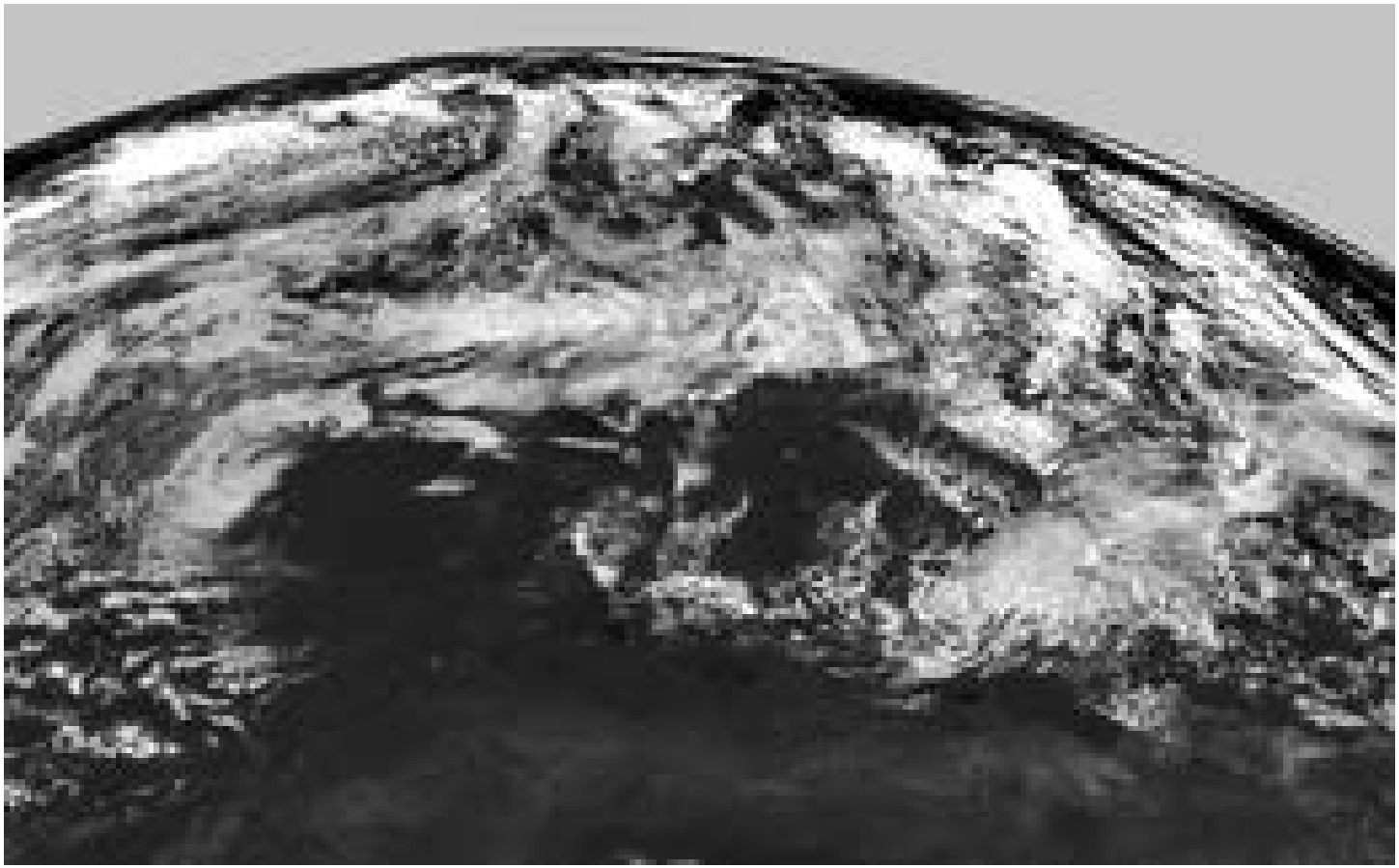


Figure: Cloudindex (date: 02 February, 2005 time: 1230 UTC)

Recurring pattern

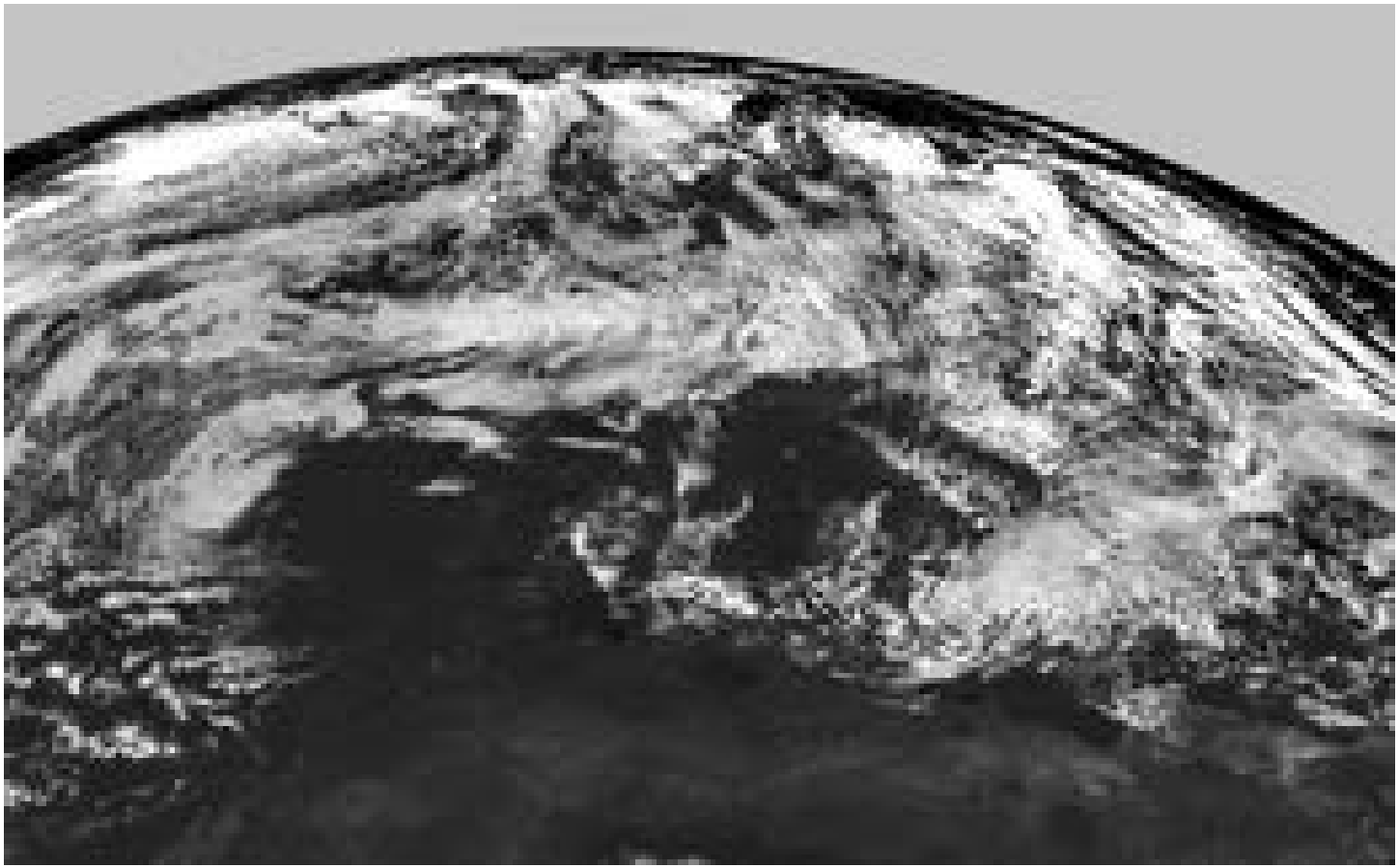


Figure: Cloudindex (date: 02 February, 2005 time: 1215 UTC)

Recurring pattern

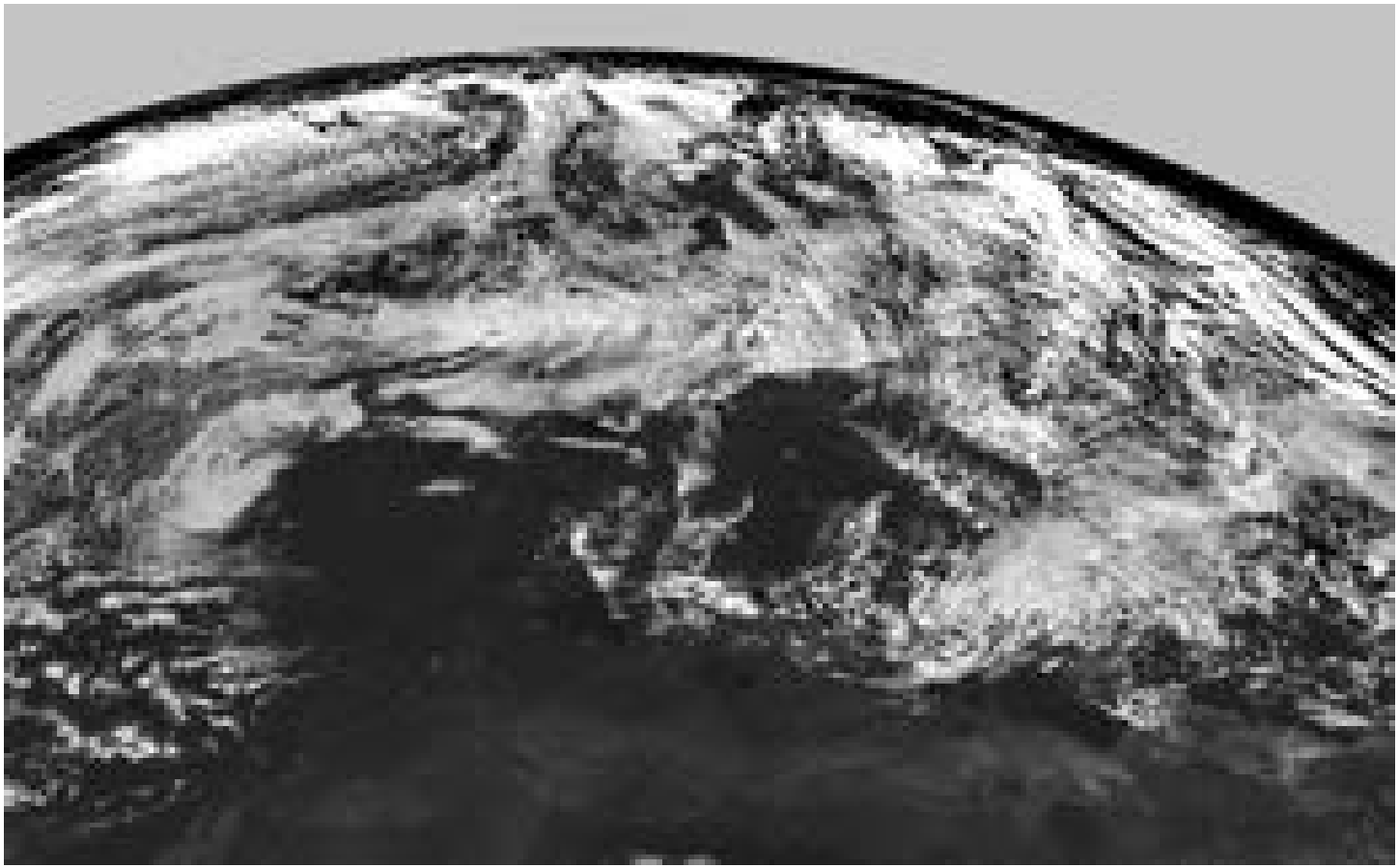


Figure: Cloudindex (date: 02 February, 2005 time: 1300 UTC)

Recurring pattern

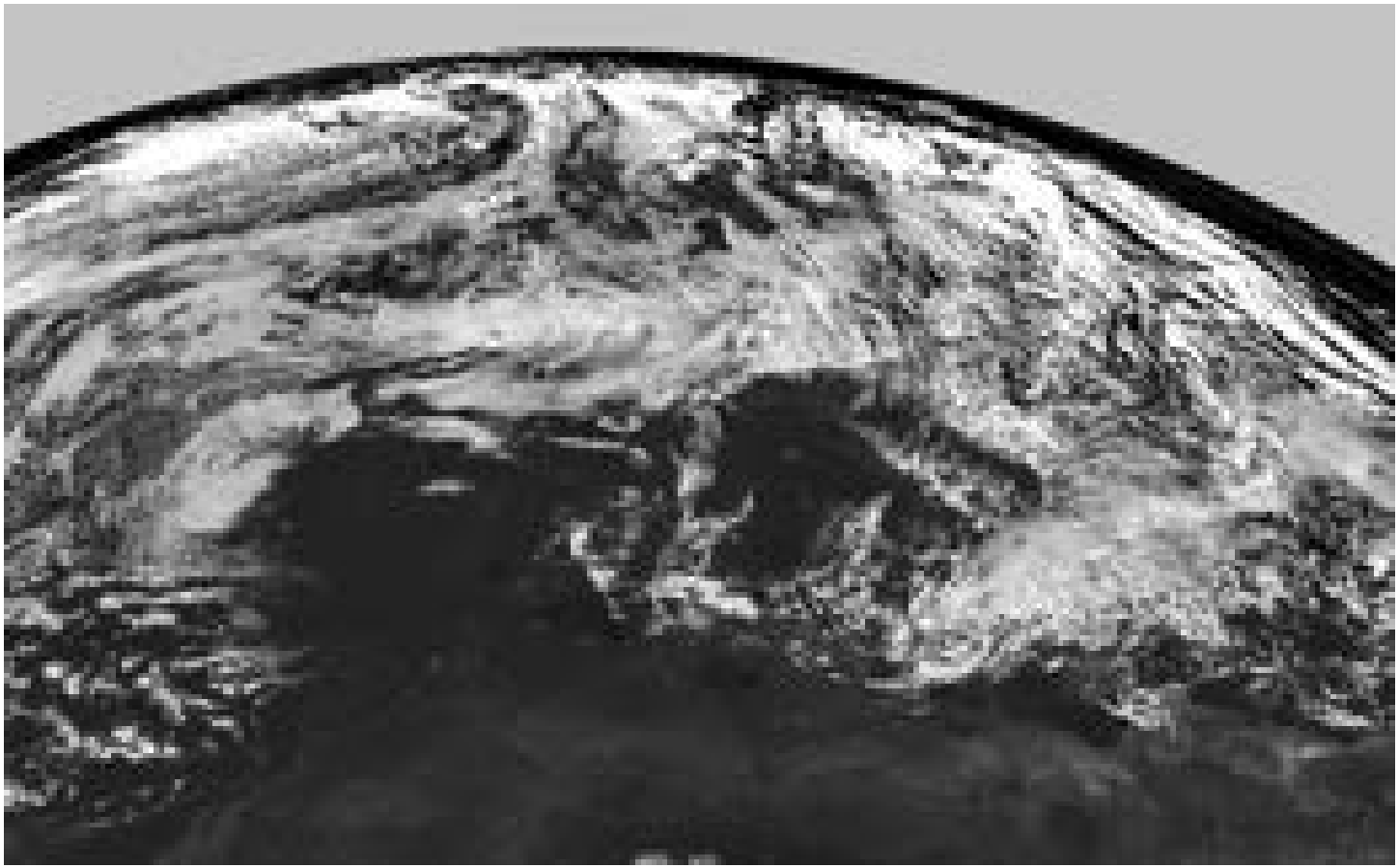


Figure: Cloudindex (date: 02 February, 2005 time: 1315 UTC)

Recurring pattern

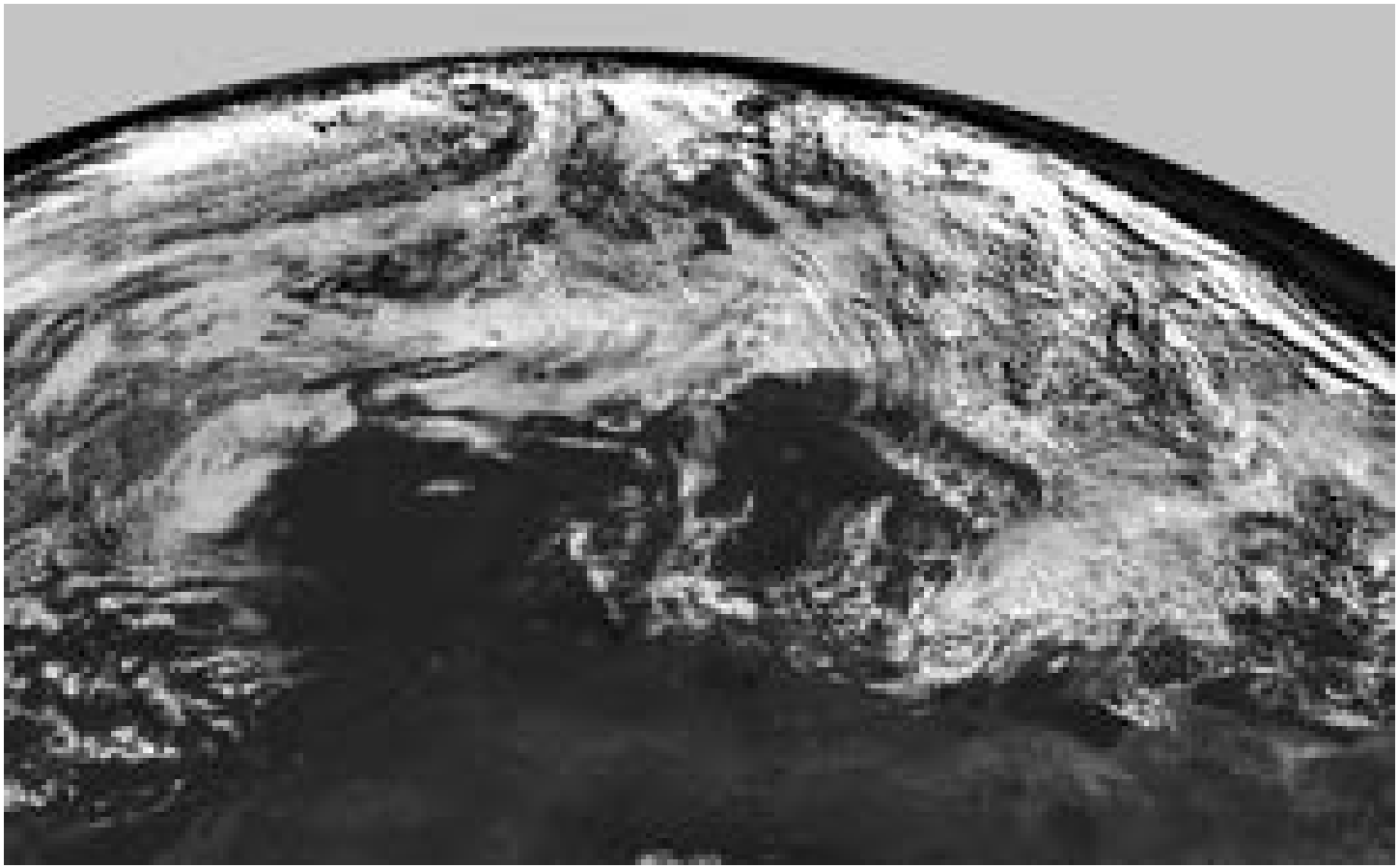


Figure: Cloudindex (date: 02 February, 2005 time: 1330 UTC)

Recurring pattern

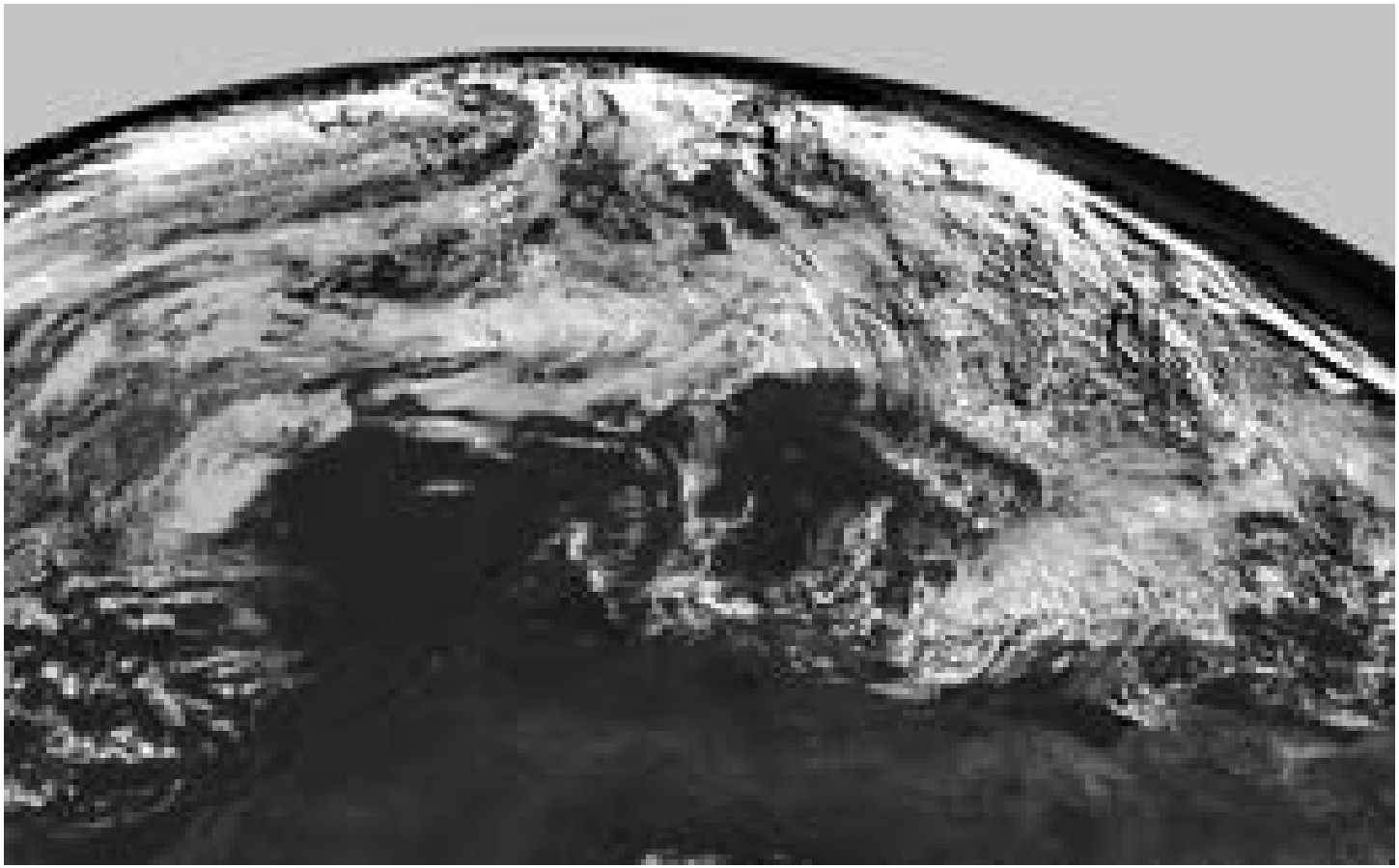


Figure: Cloudindex (date: 02 February, 2005 time: 1345 UTC)

Recurring pattern

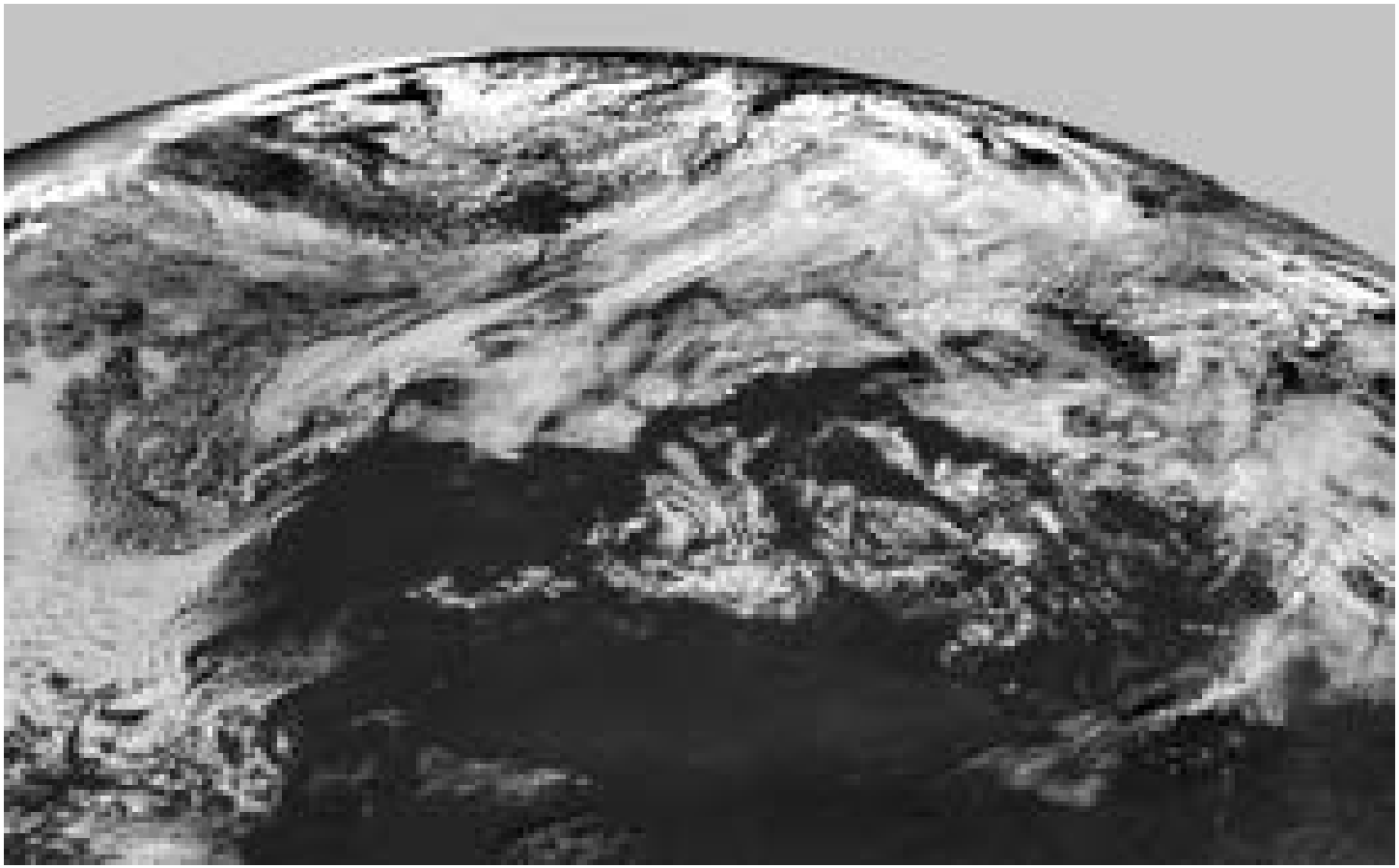


Figure: Cloudindex (date: 18 February, 2005 time: 1015 UTC)

Recurring pattern

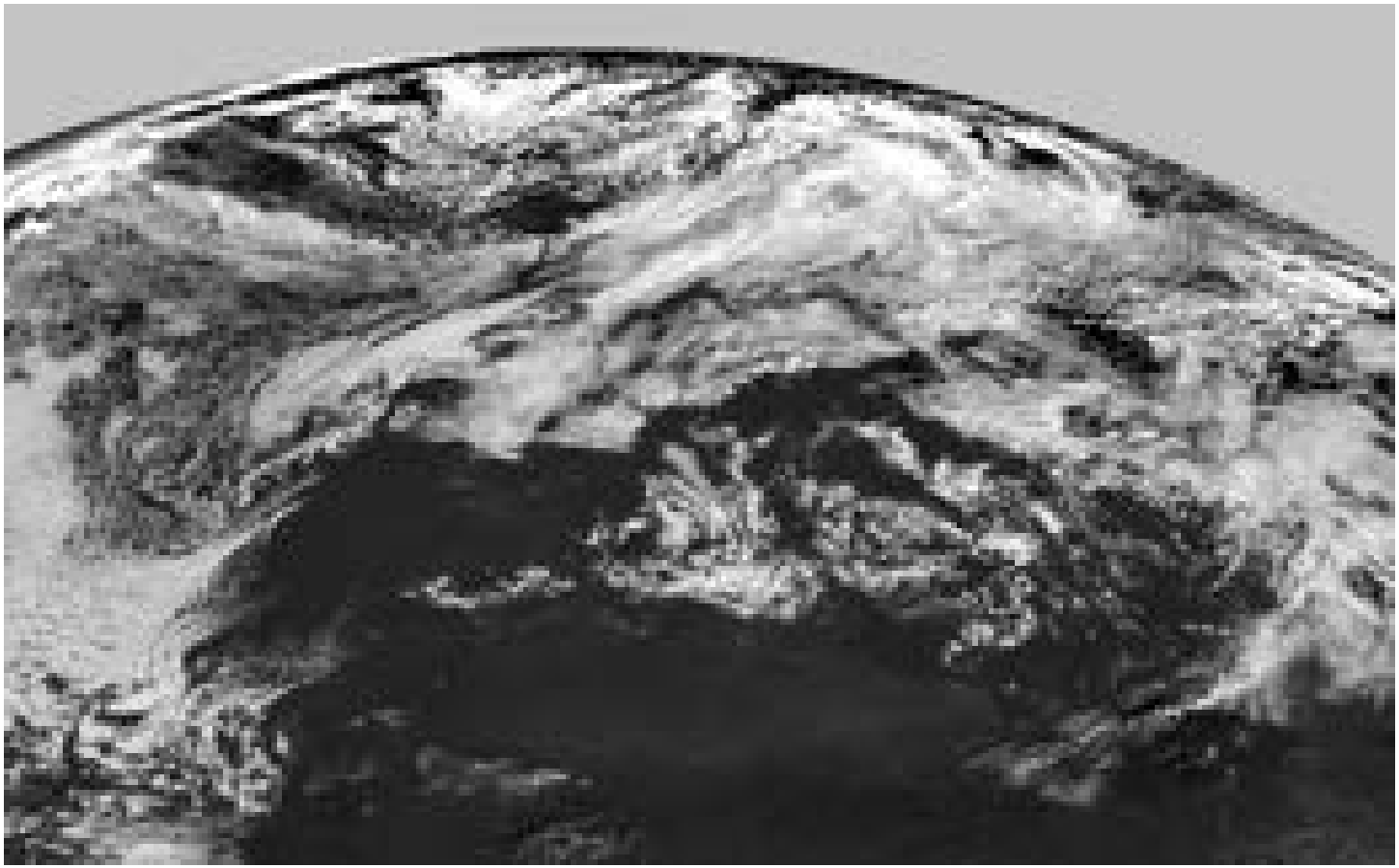


Figure: Cloudindex (date: 18 February, 2005 time: 1030 UTC)

Recurring pattern

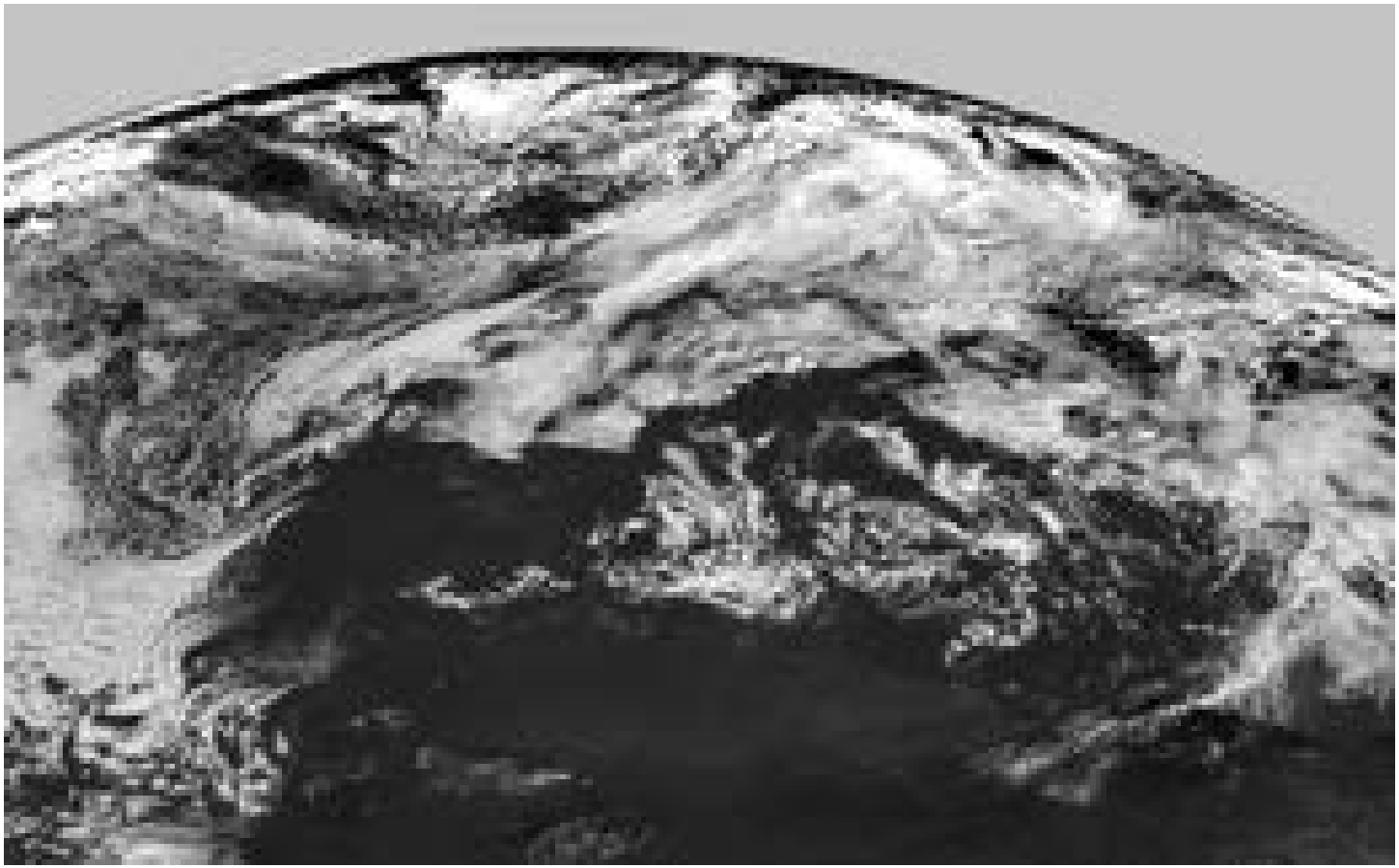


Figure: Cloudindex (date: 18 February, 2005 time: 1045 UTC)

Recurring pattern

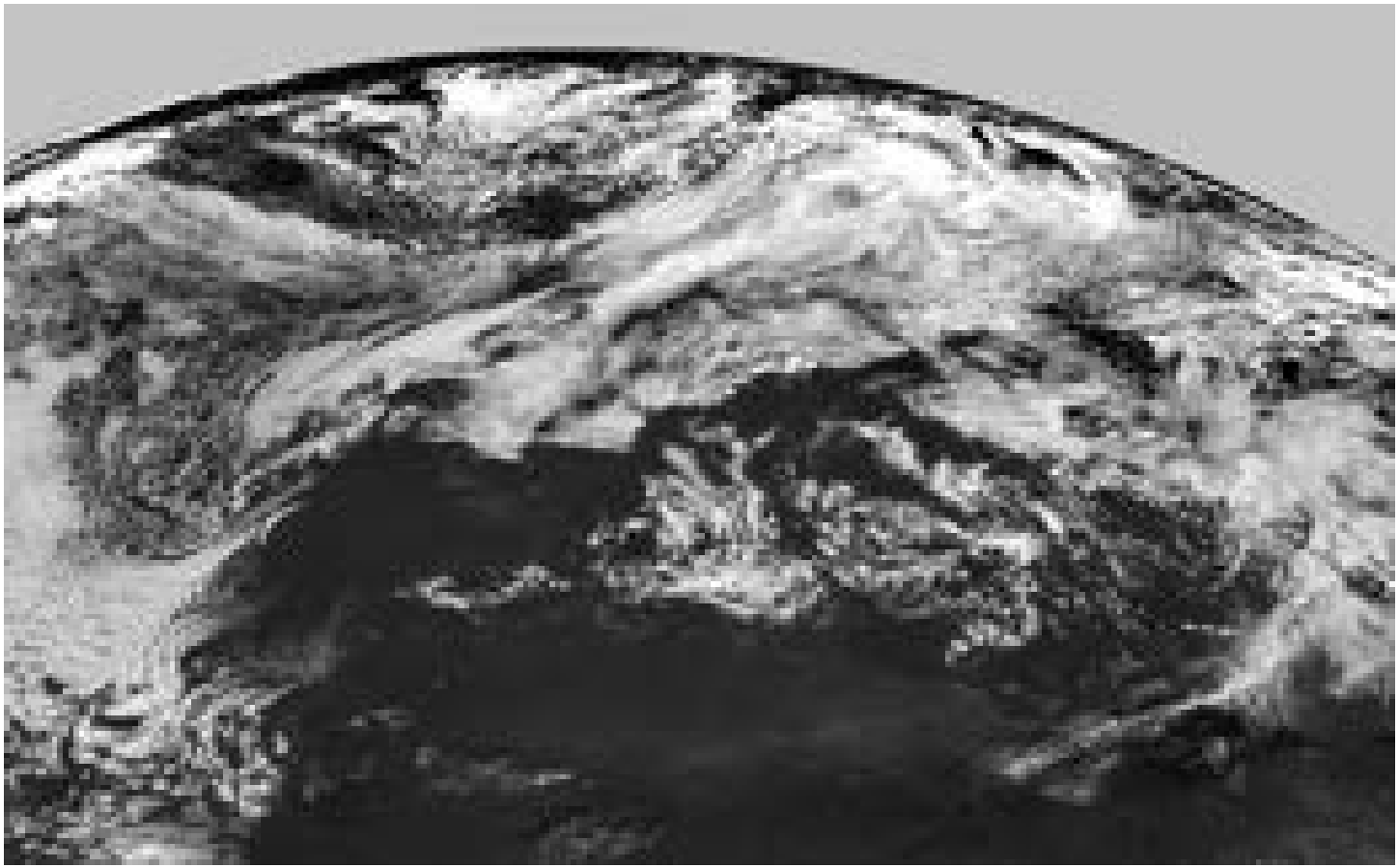


Figure: Cloudindex (date: 18 February, 2005 time: 1100 UTC)

Recurring pattern

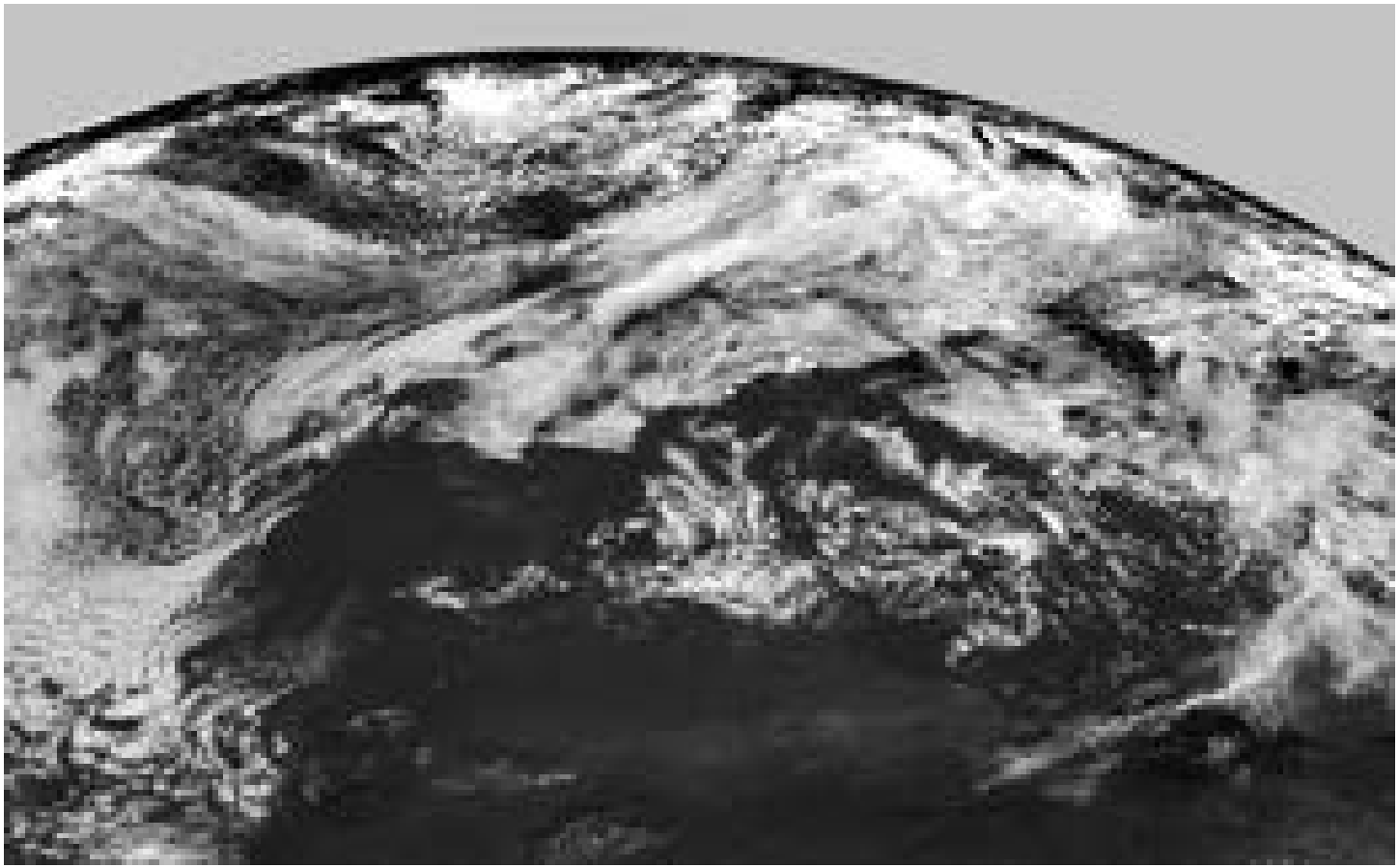


Figure: Cloudindex (date: 18 February, 2005 time: 1115 UTC)

Recurring pattern

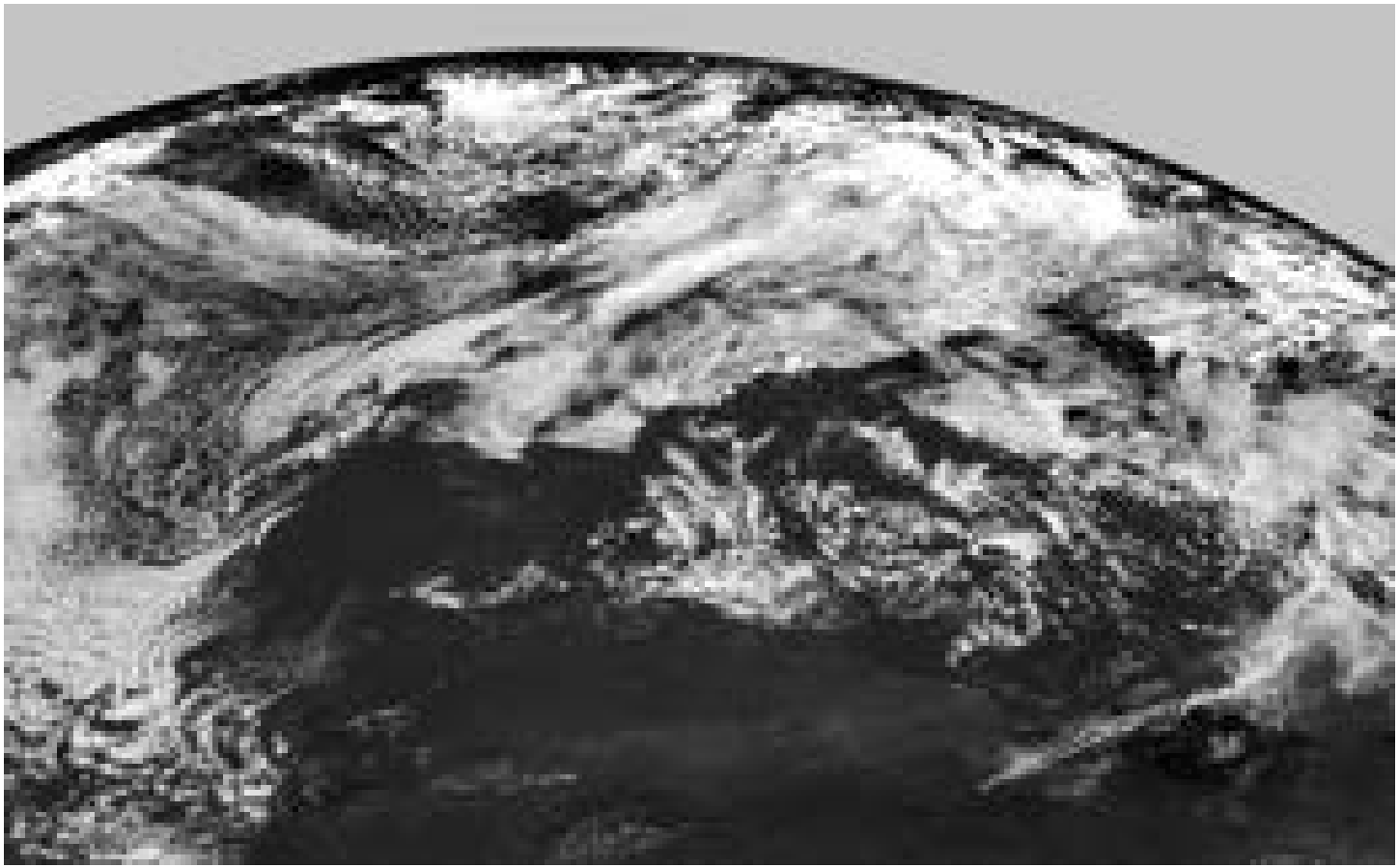


Figure: Cloudindex (date: 18 February, 2005 time: 1130 UTC)

Recurring pattern

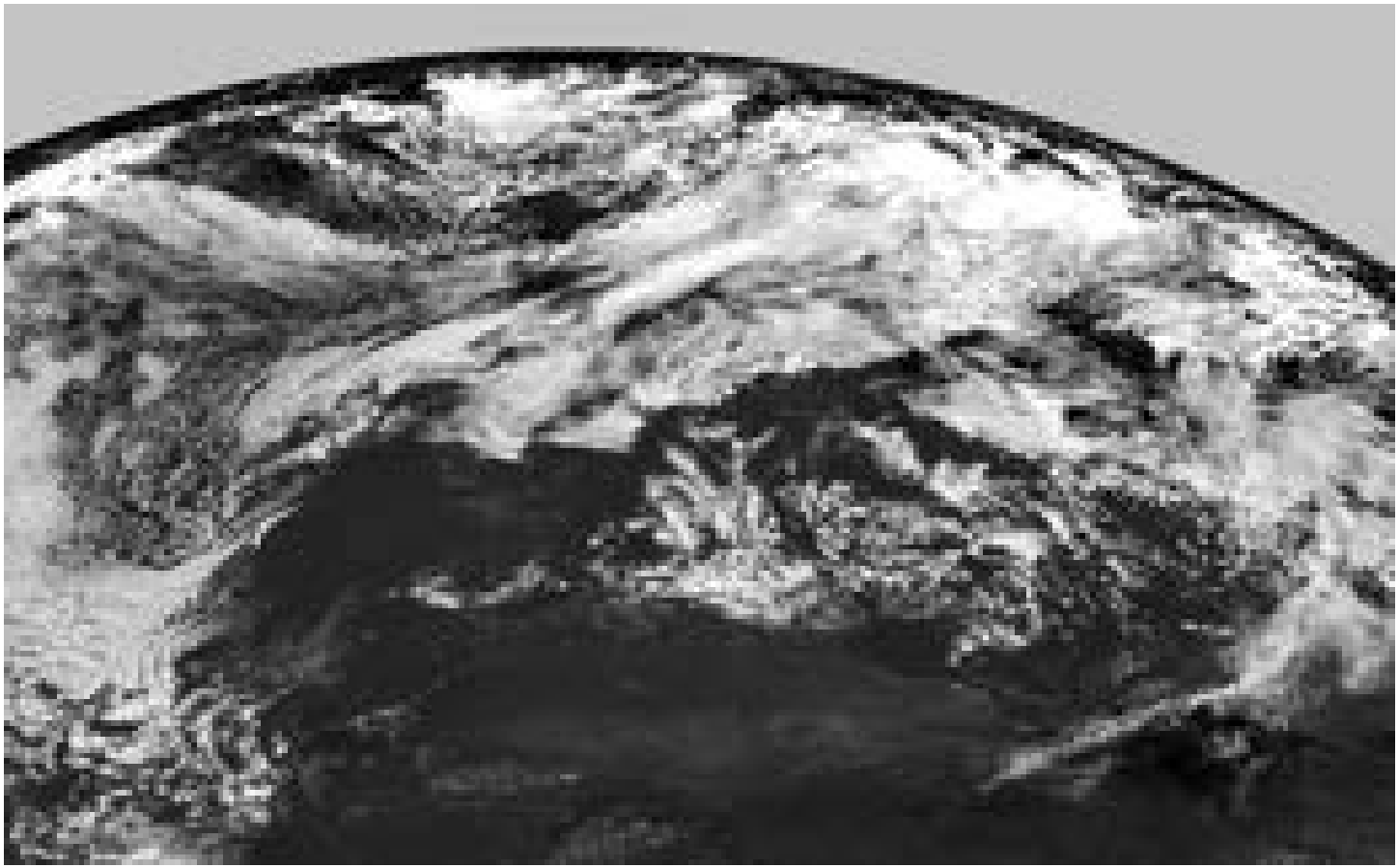


Figure: Cloudindex (date: 18 February, 2005 time: 1145 UTC)

Recurring pattern

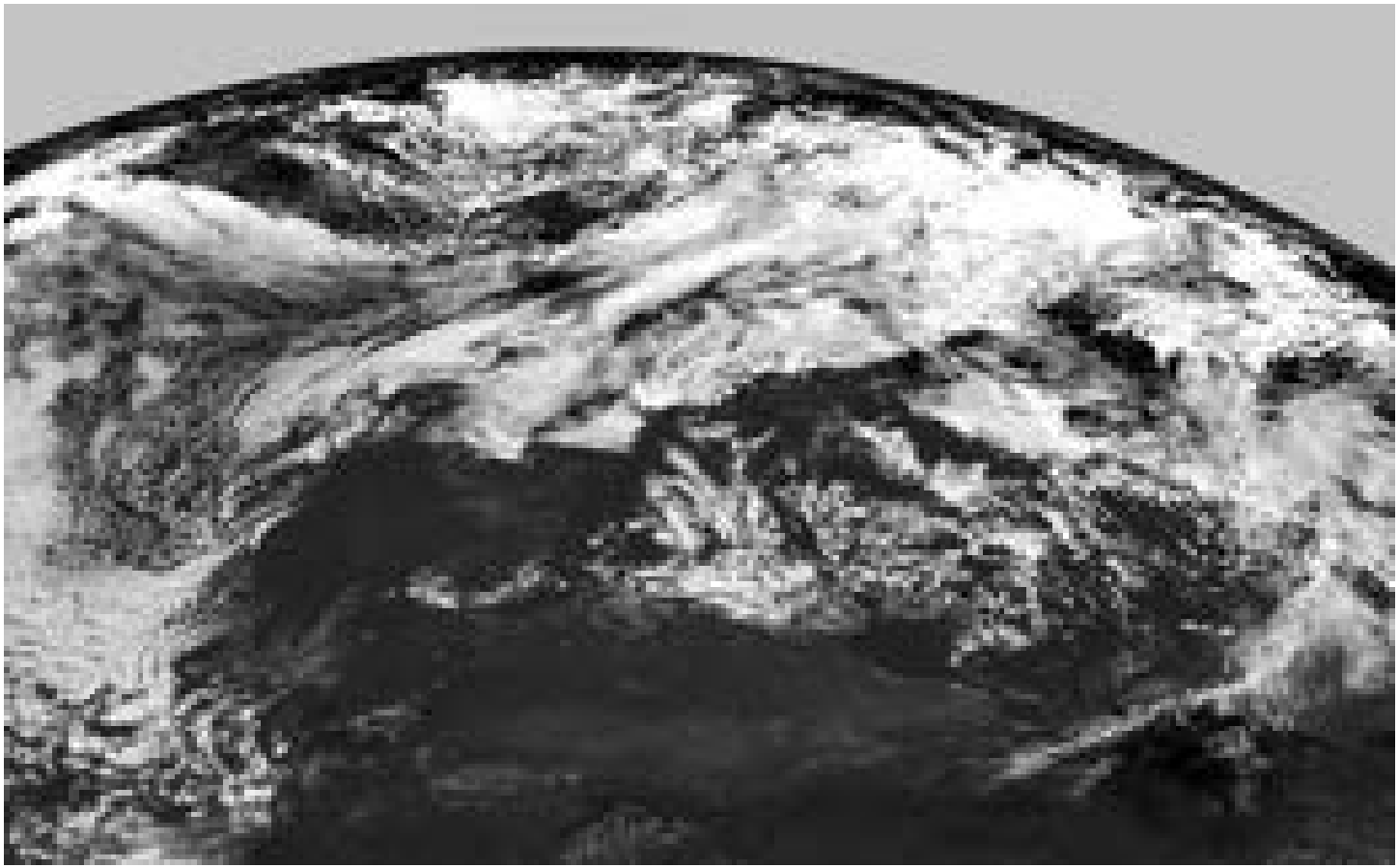


Figure: Cloudindex (date: 18 February, 2005 time: 1200 UTC)

Recurring pattern

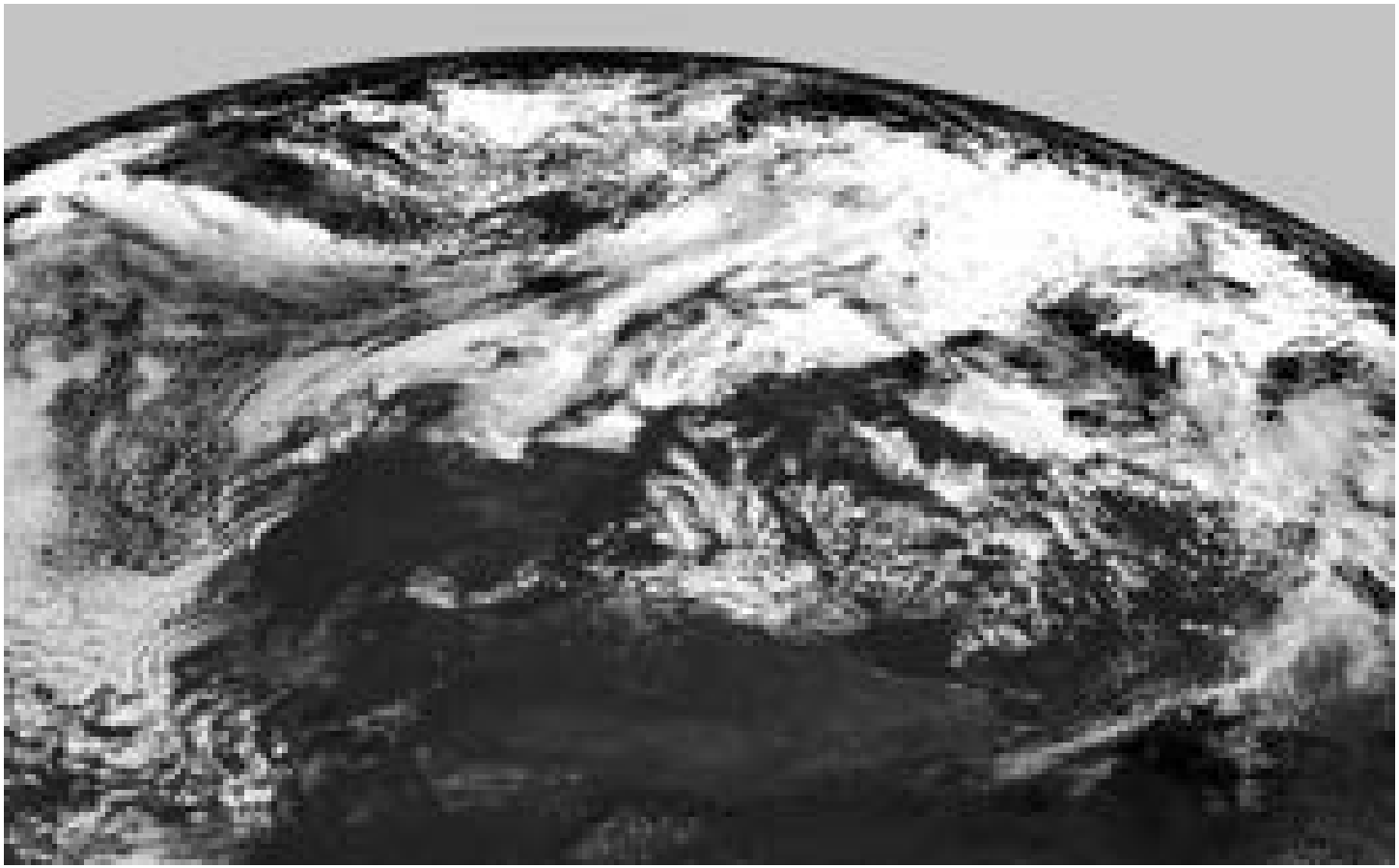


Figure: Cloudindex (date: 18 February, 2005 time: 1215 UTC)

Recurring pattern

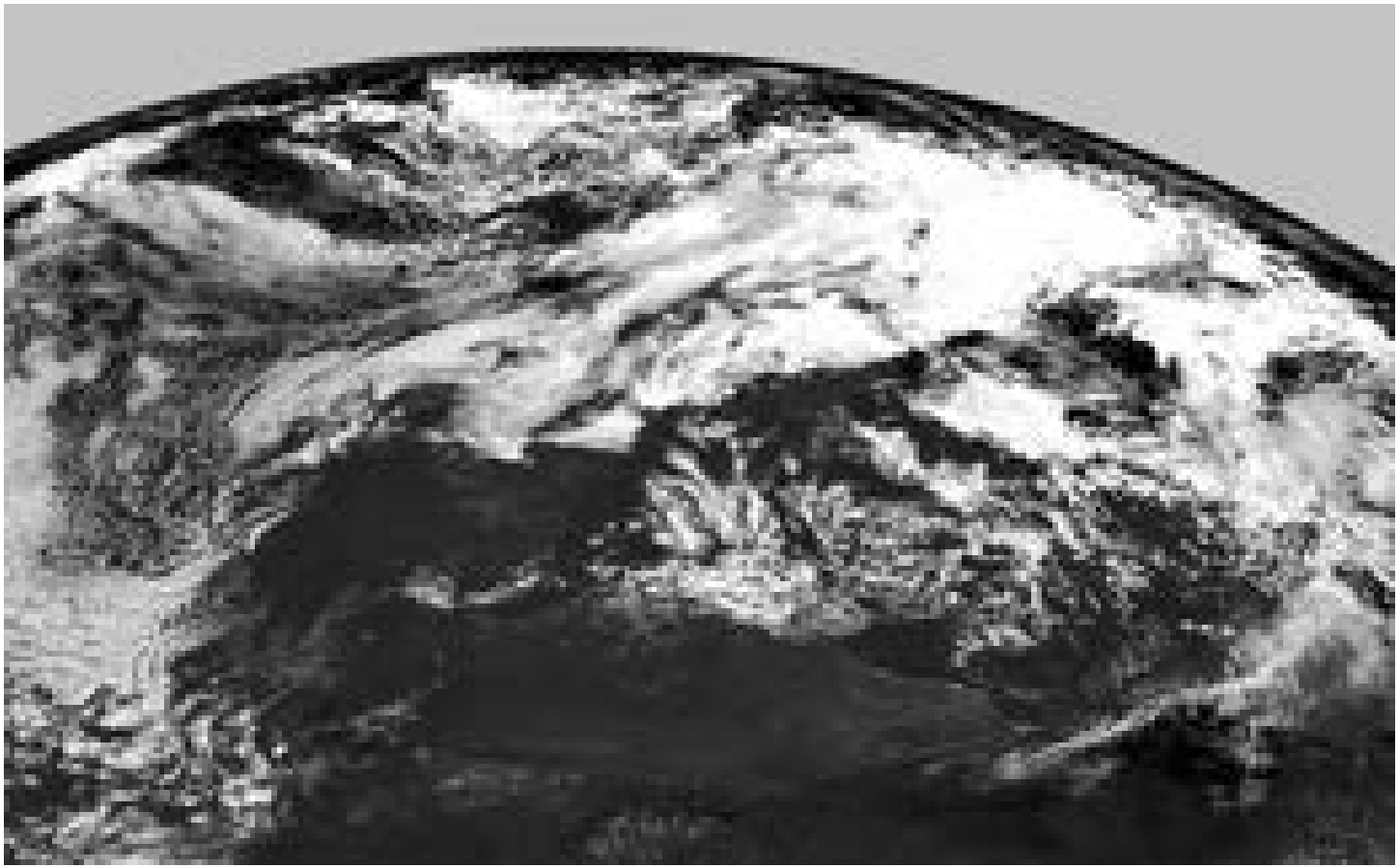


Figure: Cloudindex (date: 18 February, 2005 time: 1230 UTC)

Recurring pattern

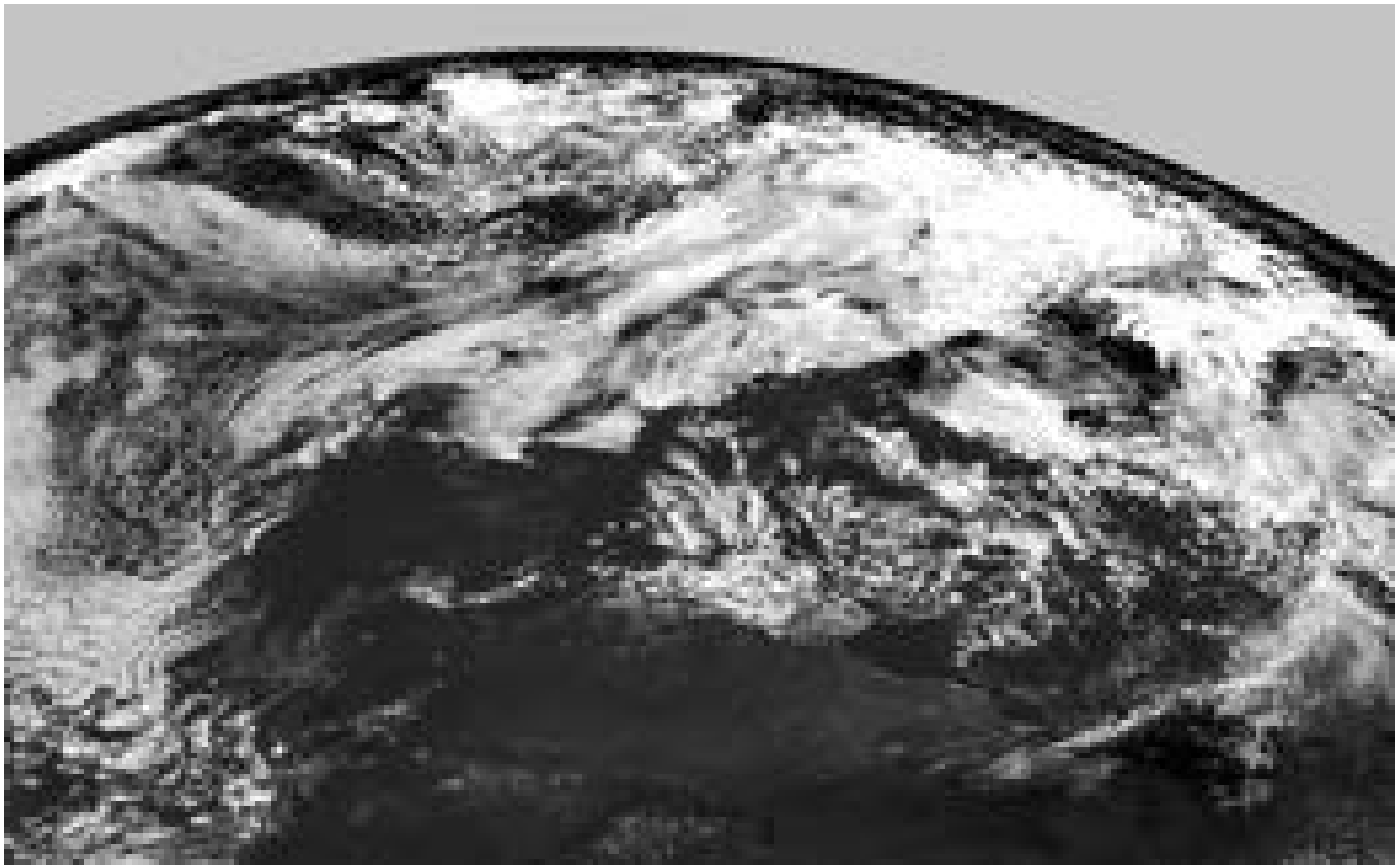


Figure: Cloudindex (date: 18 February, 2005 time: 1215 UTC)

Recurring pattern

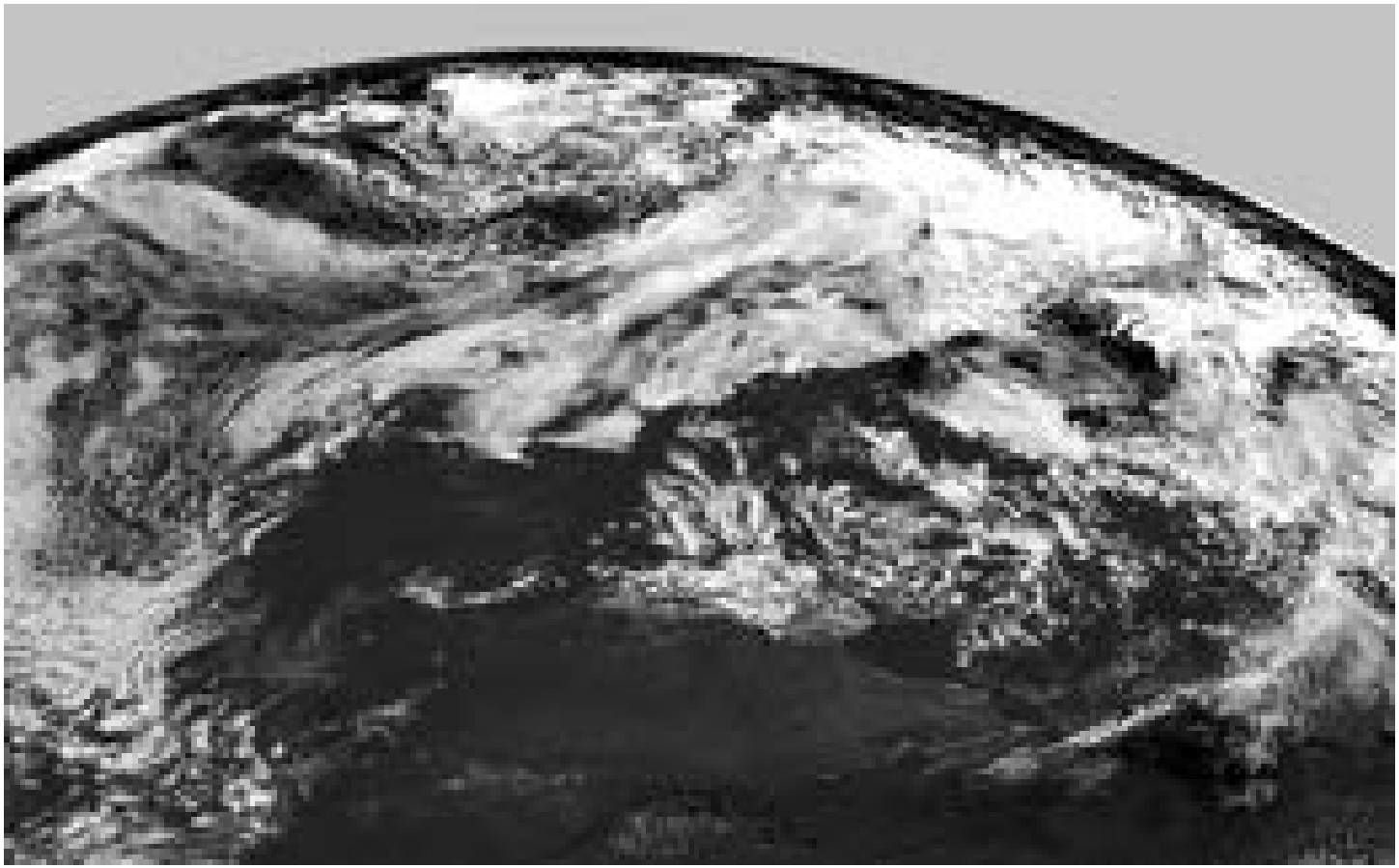


Figure: Cloudindex (date: 18 February, 2005 time: 1300 UTC)

Recurring pattern

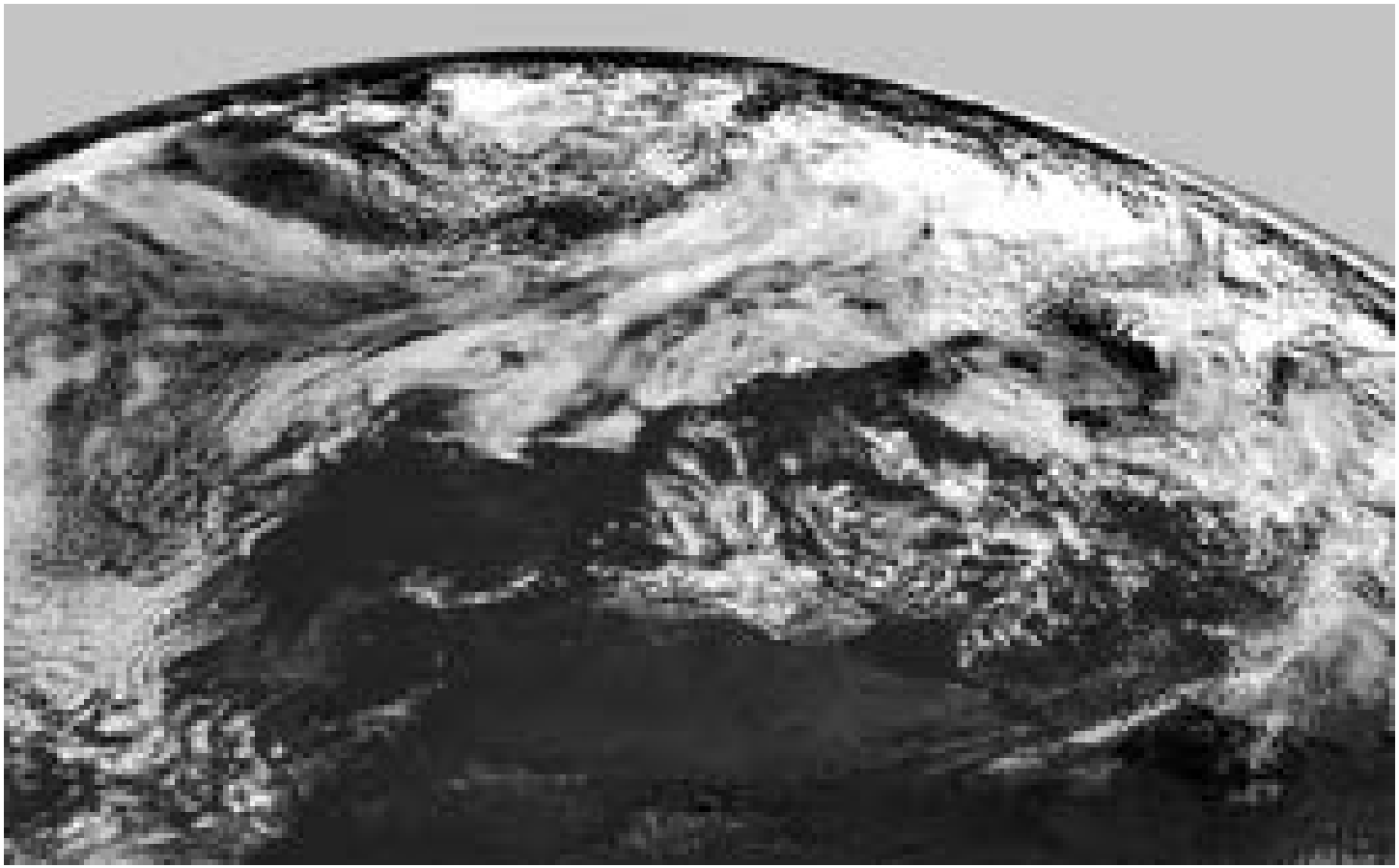


Figure: Cloudindex (date: 18 February, 2005 time: 1315 UTC)

Recurring pattern

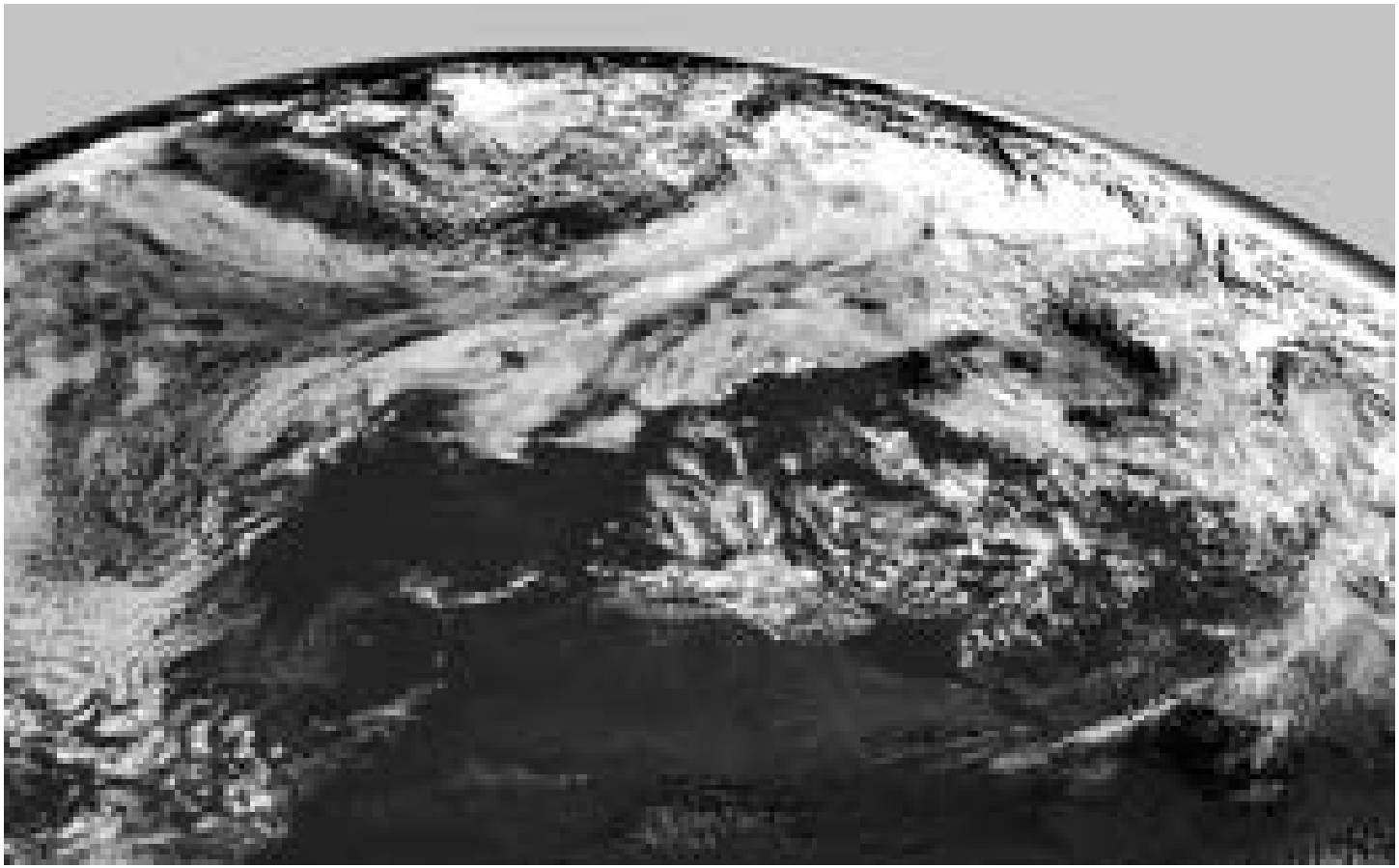


Figure: Cloudindex (date: 18 February, 2005 time: 1330 UTC)

Recurring pattern

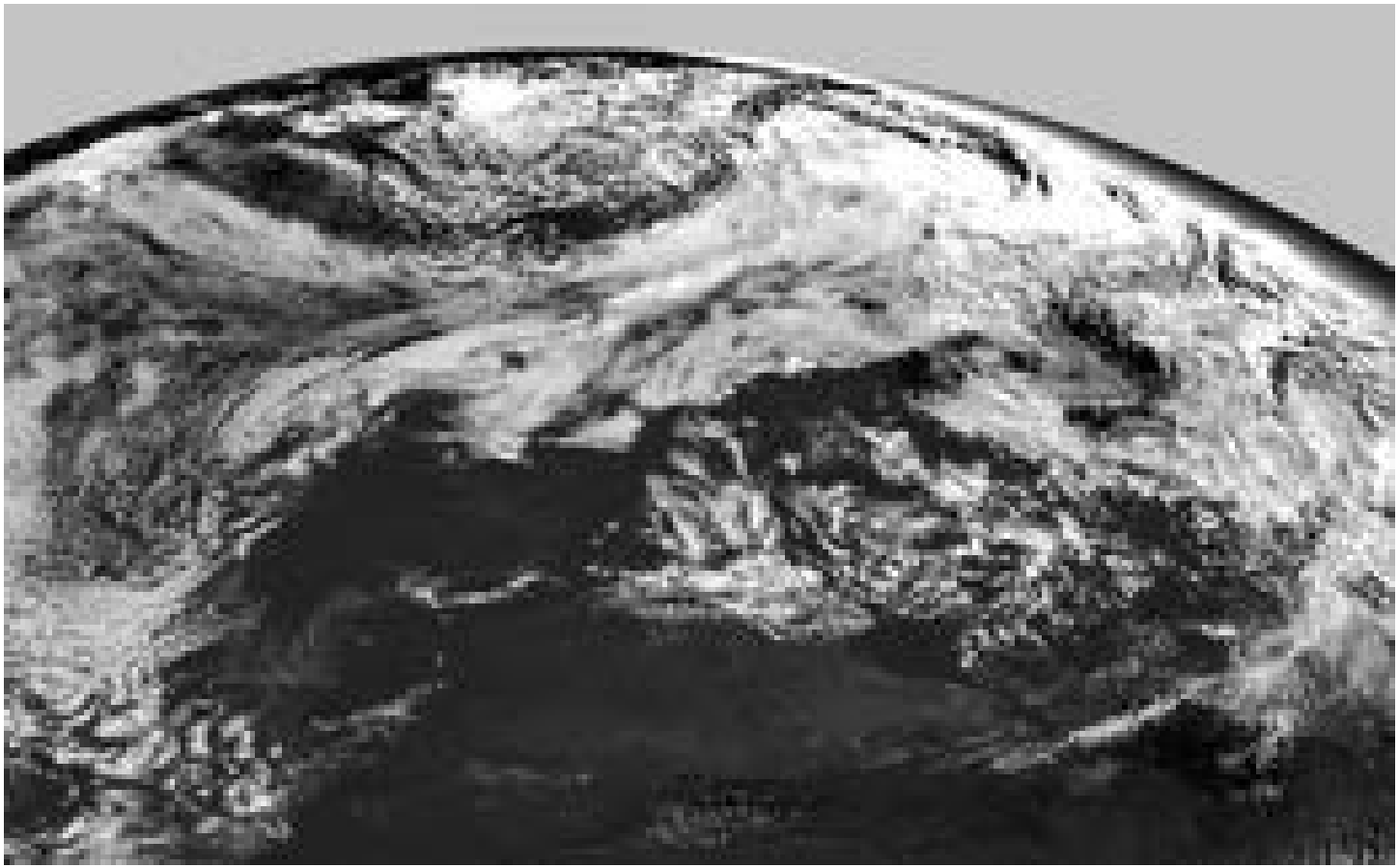


Figure: Cloudindex (date: 18 February, 2005 time: 1345 UTC)

Identifying the problems

Problem 1: Defective images

- Images with strange artifacts
- Issues with image headers
- Corrupted images can be few pixels shifted
- Complete day missing due to technical reasons

Note: weird artifacts in one raw image may get transferred to all days of month

Issues with image headers

For certain days and certain time slots, the numerical values of certain parameters in image header were found erronous. There were differences in orders of magnitude.

For example, all days of March, 2006 at 04:15 UTC had ρ_{max} values of 679.022043. However, on 12 March, 2006, this value was found to be 18.668960, although no strange feature was seen in the image itself.

Identifying the problems

Problem 1: Defective images

- Images with strange artifacts
- Issues with image headers
- Corrupted images can be few pixels shifted
- Complete day missing due to technical reasons

Note: weird artifacts in one raw image may get transferred to all days of month

Explaining Problem 1

Figure: Cloudindex (date: 03 July, 2007 time: 0700 UTC)

Explaining Problem 1

Figure: Cloudindex (date: 03 July, 2007 time: 0715 UTC)

Explaining Problem 1

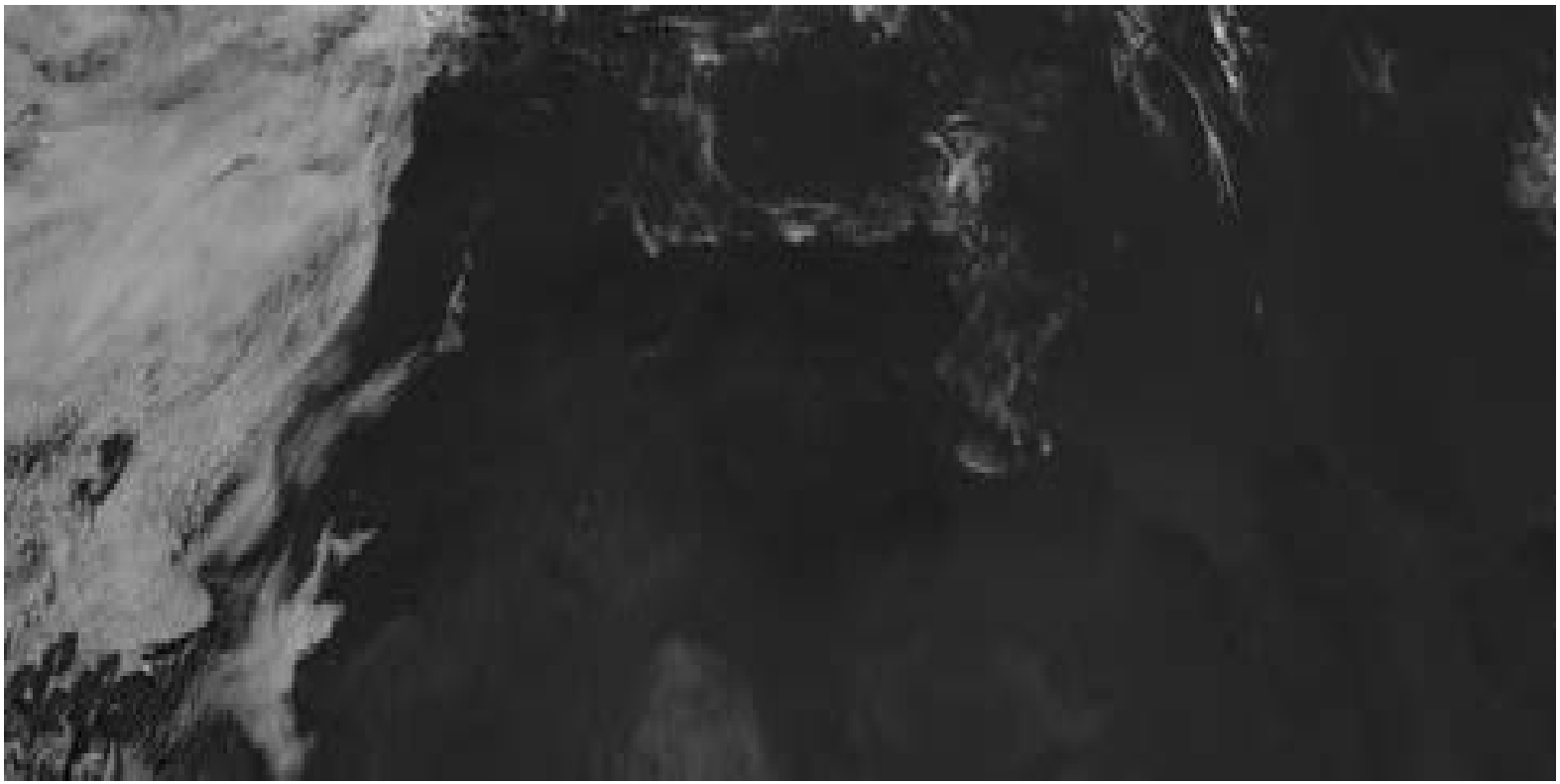


Figure: Cloudindex (date: 03 July, 2007 time: 0730 UTC)

Explaining Problem 1

Figure: Cloudindex (date: 03 July, 2007 time: 0745 UTC)

Explaining Problem 1

Figure: Cloudindex (date: 03 July, 2007 time: 0800 UTC)

Explaining Problem 1

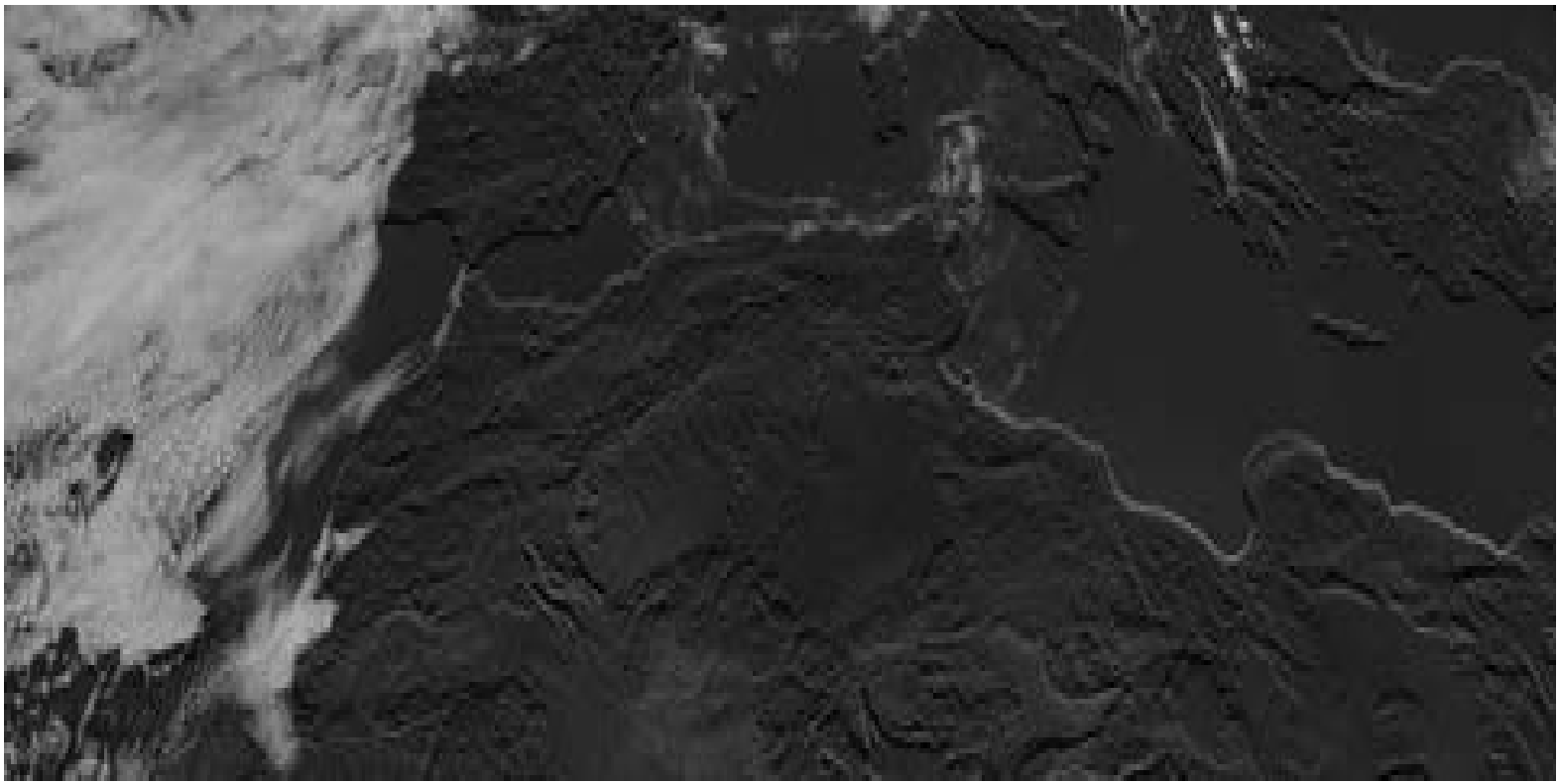


Figure: Cloudindex (date: 03 July, 2007 time: 0815 UTC)

Explaining Problem 1

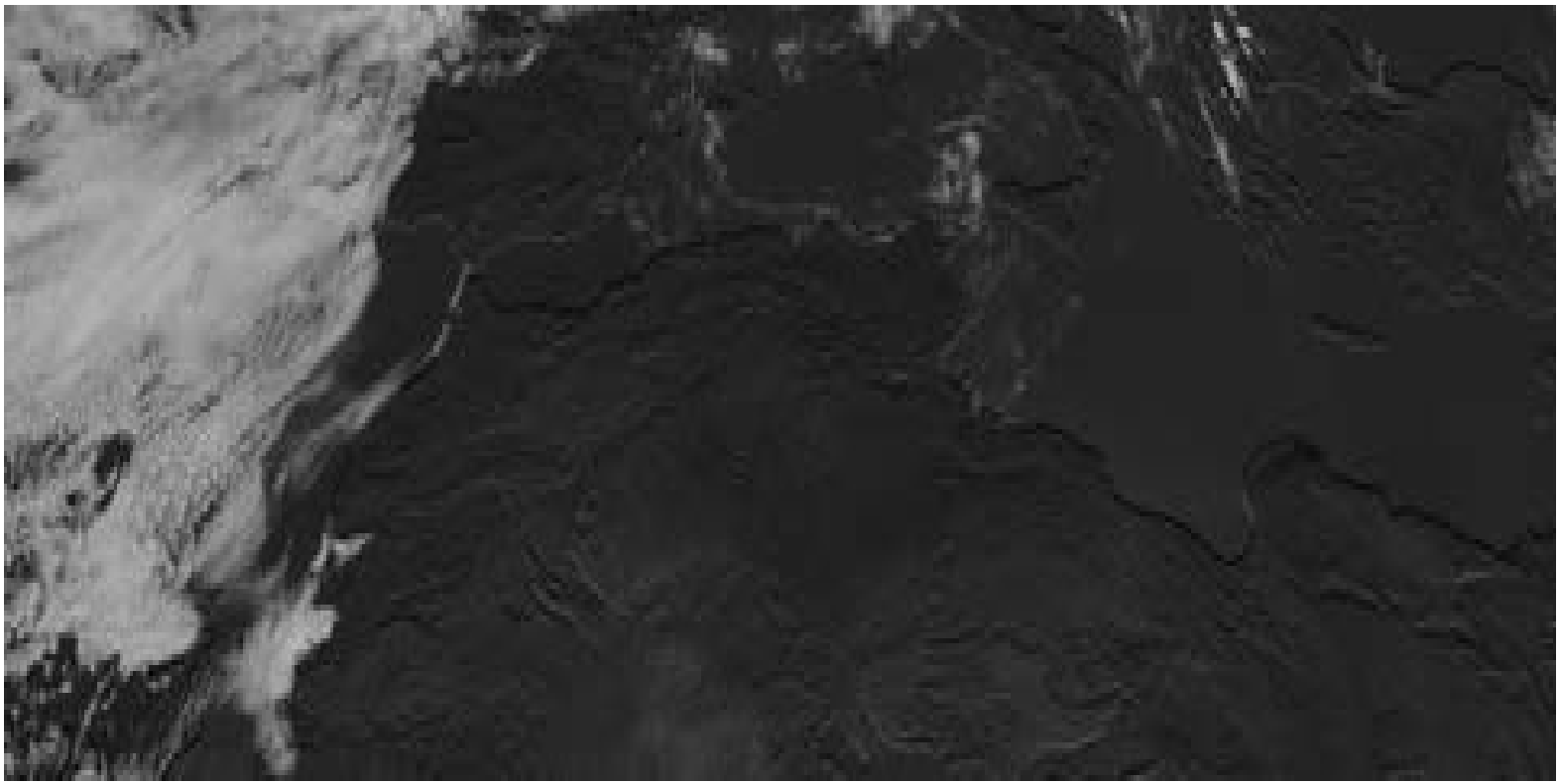


Figure: Cloudindex (date: 03 July, 2007 time: 0830 UTC)

Explaining Problem 1

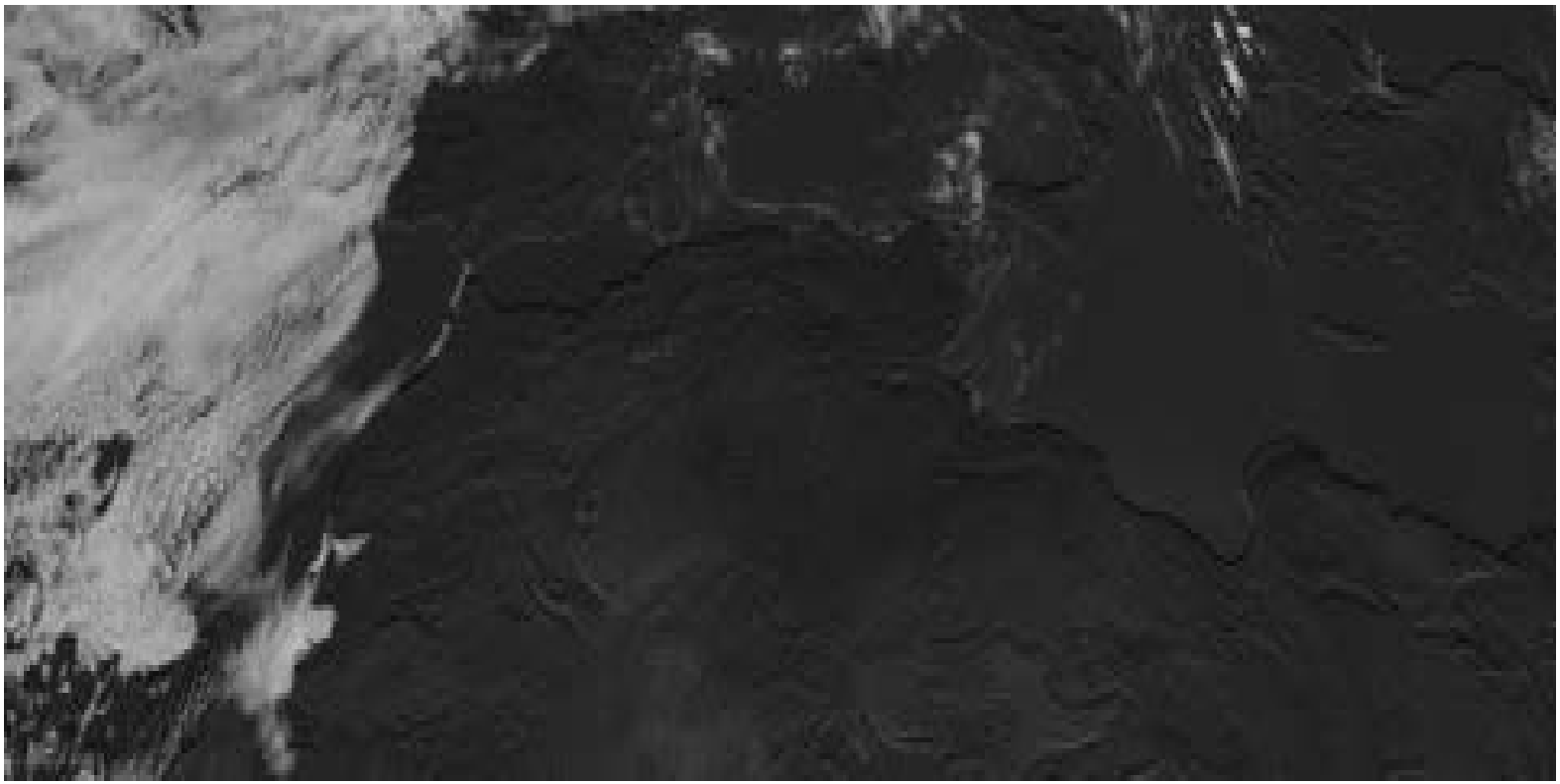


Figure: Cloudindex (date: 03 July, 2007 time: 0845 UTC)

Explaining Problem 1

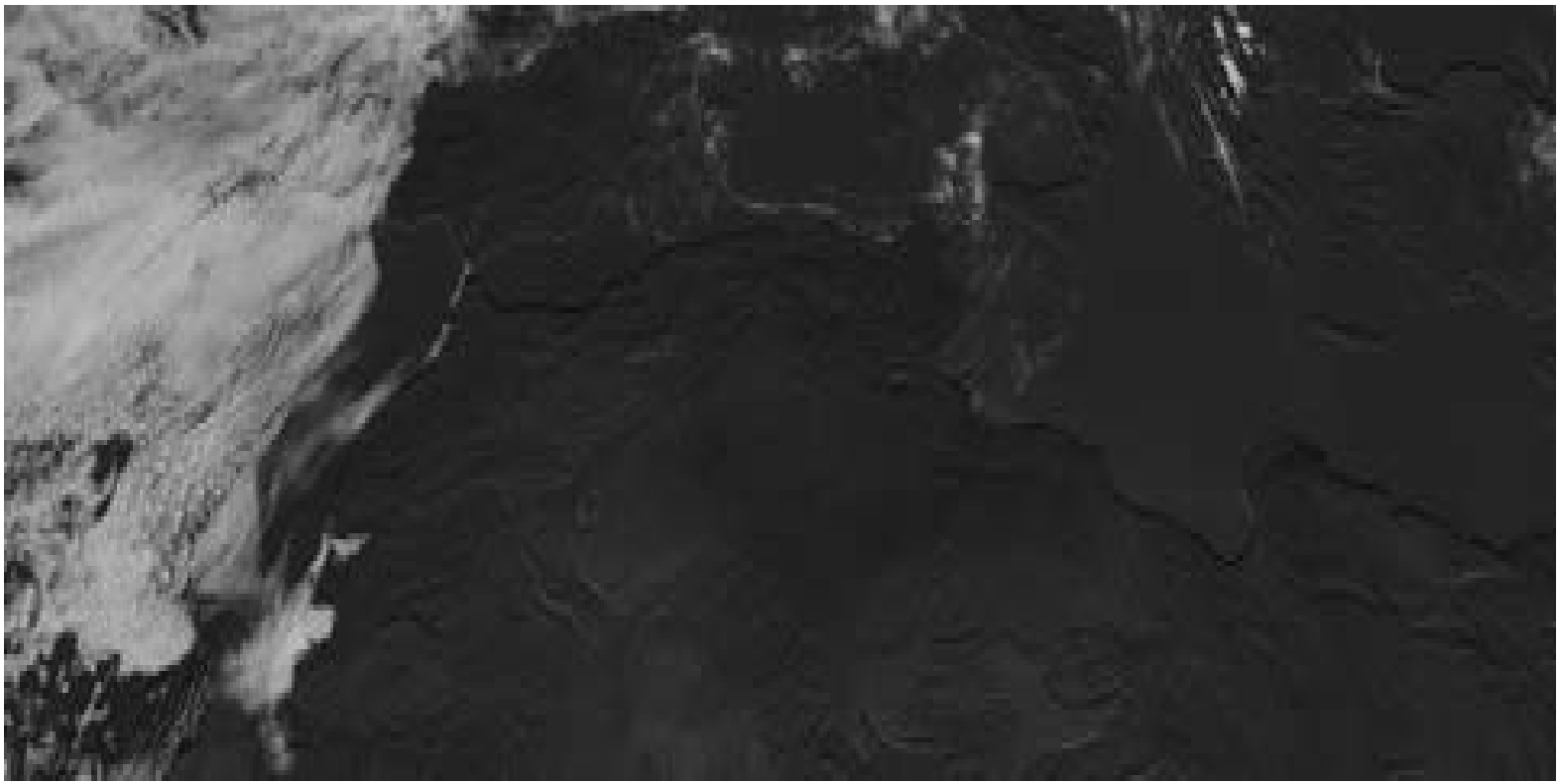


Figure: Cloudindex (date: 03 July, 2007 time: 0900 UTC)

Identifying the problems

Problem 1: Defective images

- Images with strange artifacts
- Issues with image headers
- Corrupted images can be few pixels shifted
- Complete day missing due to technical reasons

For example, 24th September, 2006 is a transition day between MSG1 (Meteosat-8) and MSG2 (Meteosat-9) satellites and all sensors were down

Identifying the problems

Problem 2: Anisotropic reflection

- Since surface reflection is not completely isotropic, the signal received by the satellite also depends on the sun-satellite geometry
- When sun-satellite in line, specially around noon-time, some brightening effects may be observed
- These are then misinterpreted as clouds, and overall lower irradiance is infered

Note: dark areas in satellite images are interpreted as cloud-free regions, while bright regions are taken as cloudy

Explaining Problem 2

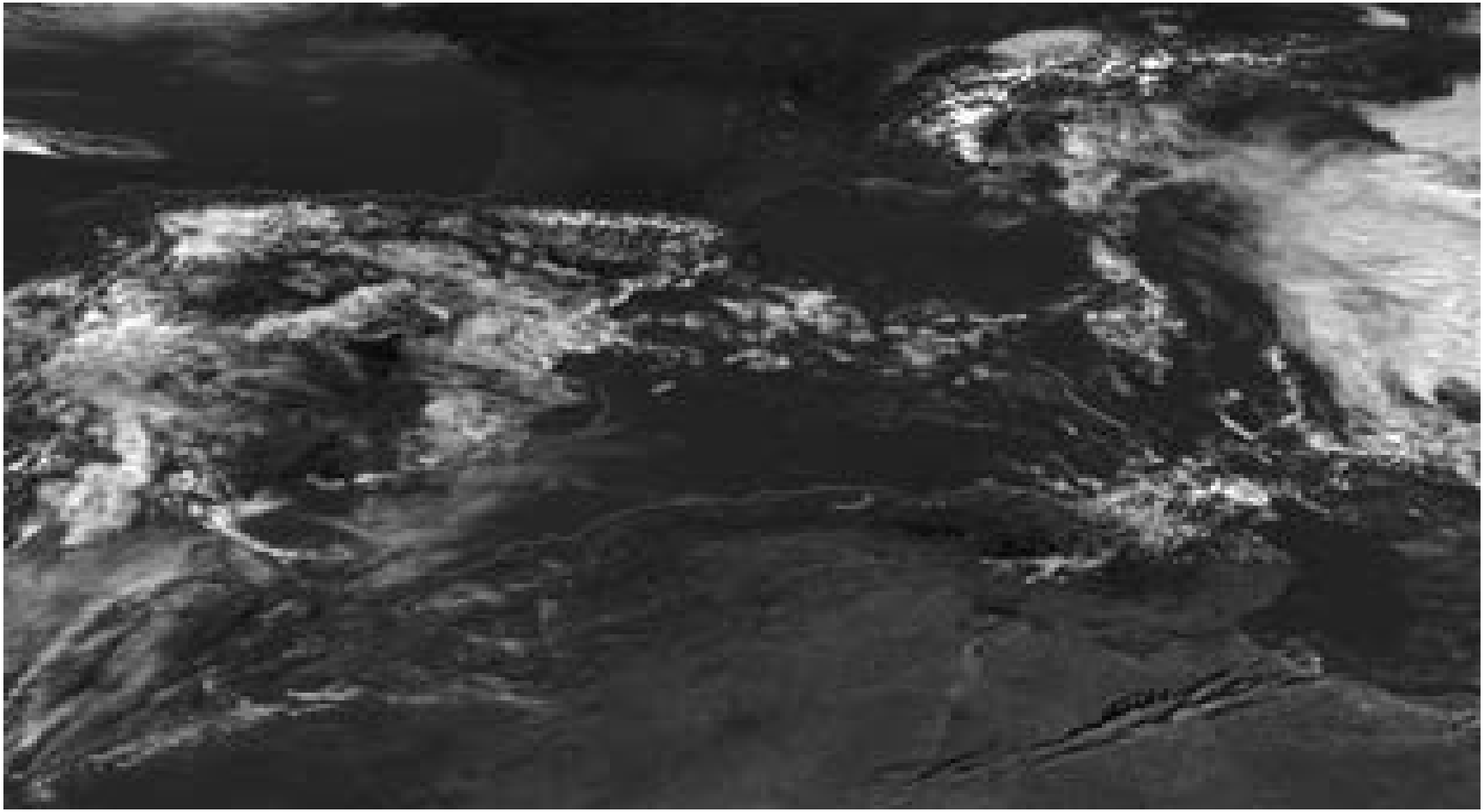


Figure: Cloudindex (date: 05 March, 2011 time: 1100 UTC

Explaining Problem 2

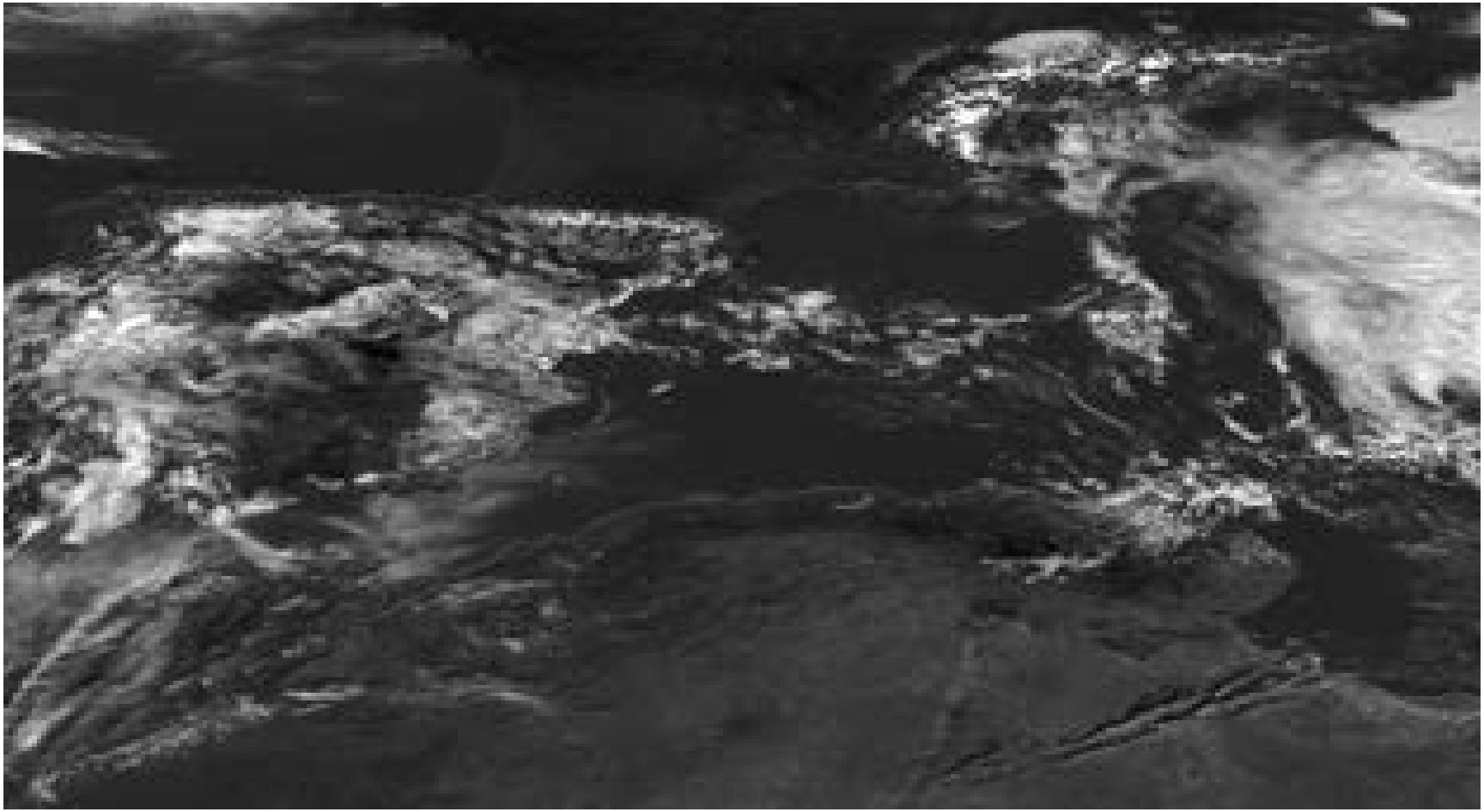


Figure: Cloudindex (date: 05 March, 2011 time: 1115 UTC

Explaining Problem 2

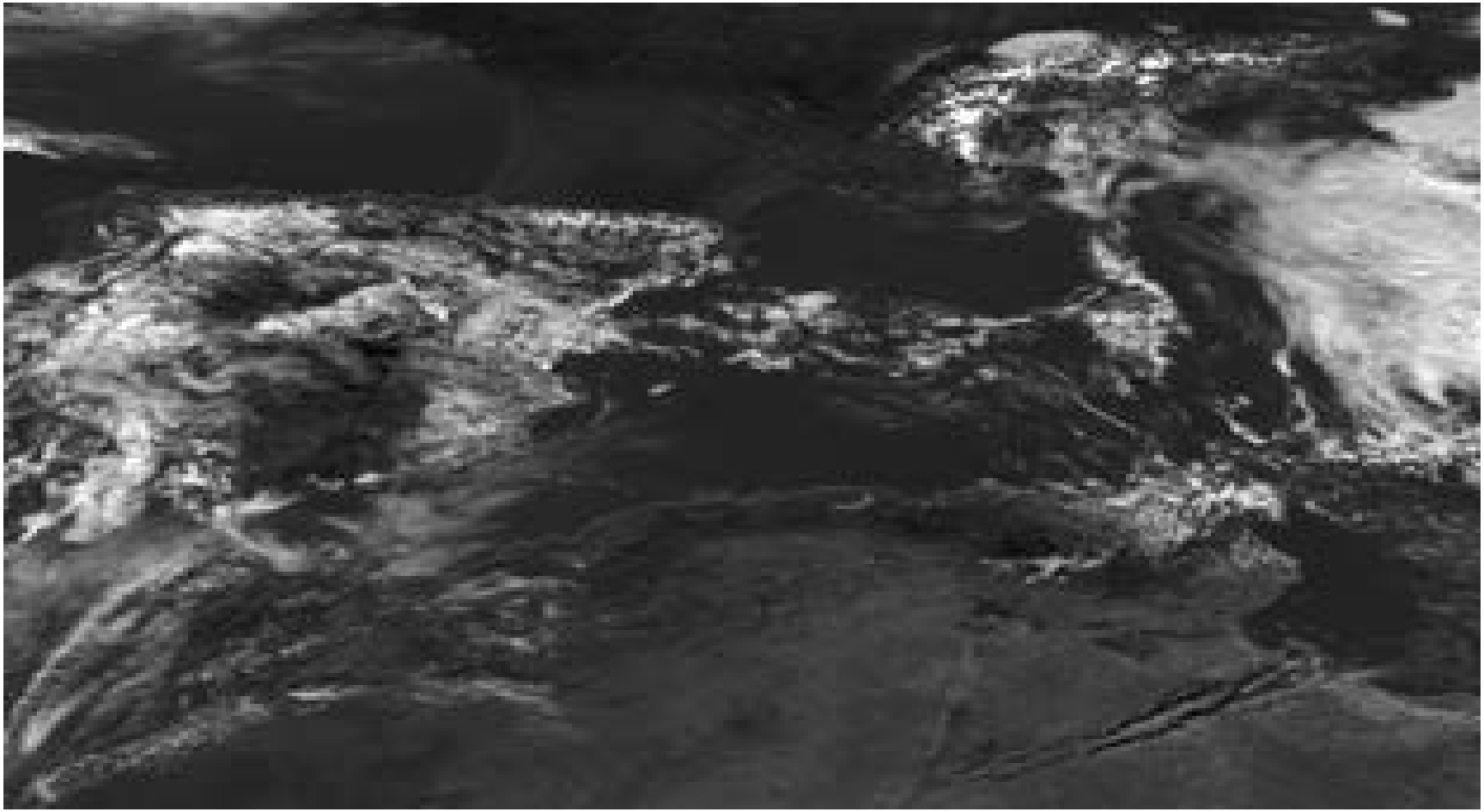


Figure: Cloudindex (date: 05 March, 2011 time: 1130 UTC

Explaining Problem 2

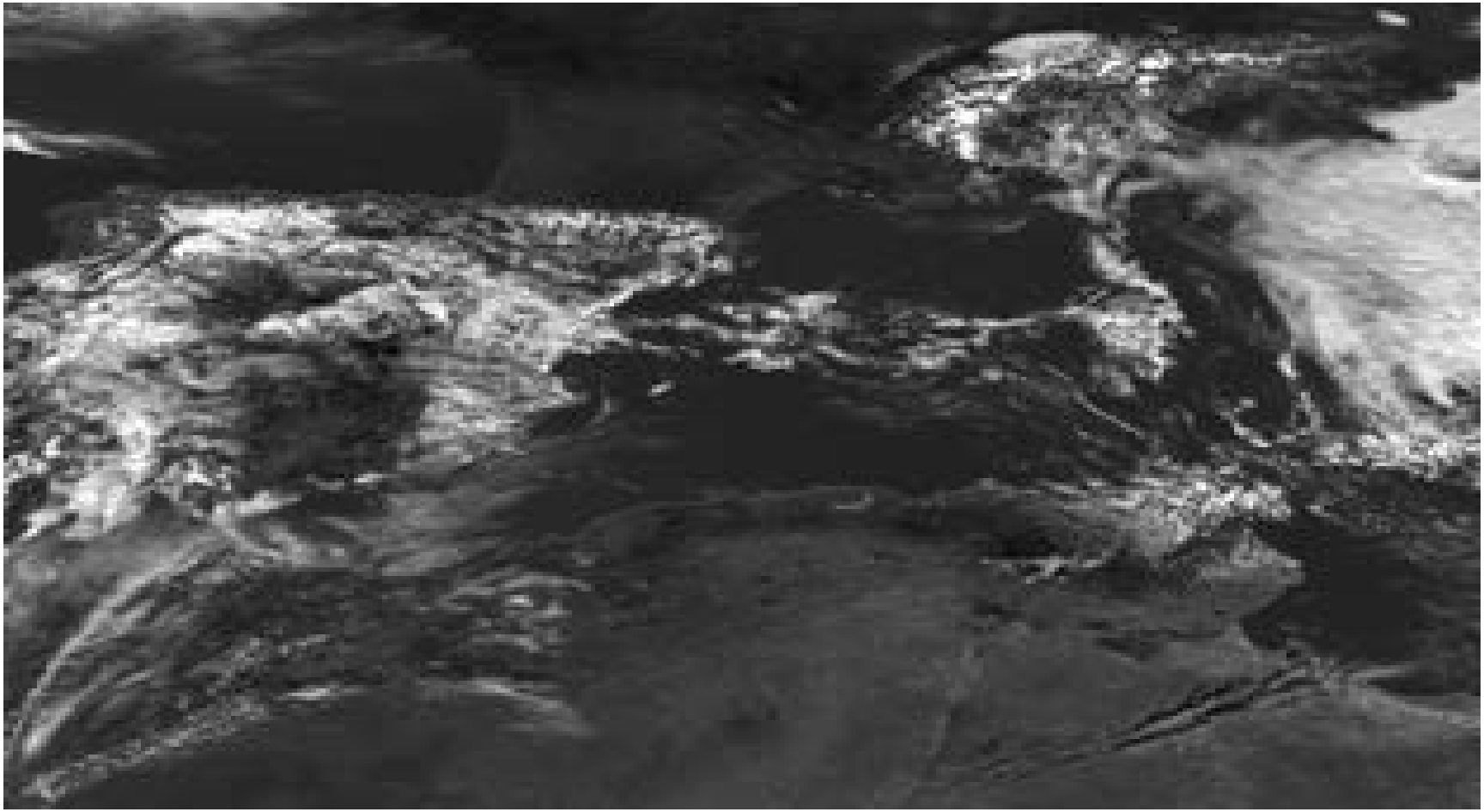


Figure: Cloudindex (date: 05 March, 2011 time: 1145 UTC

Explaining Problem 2

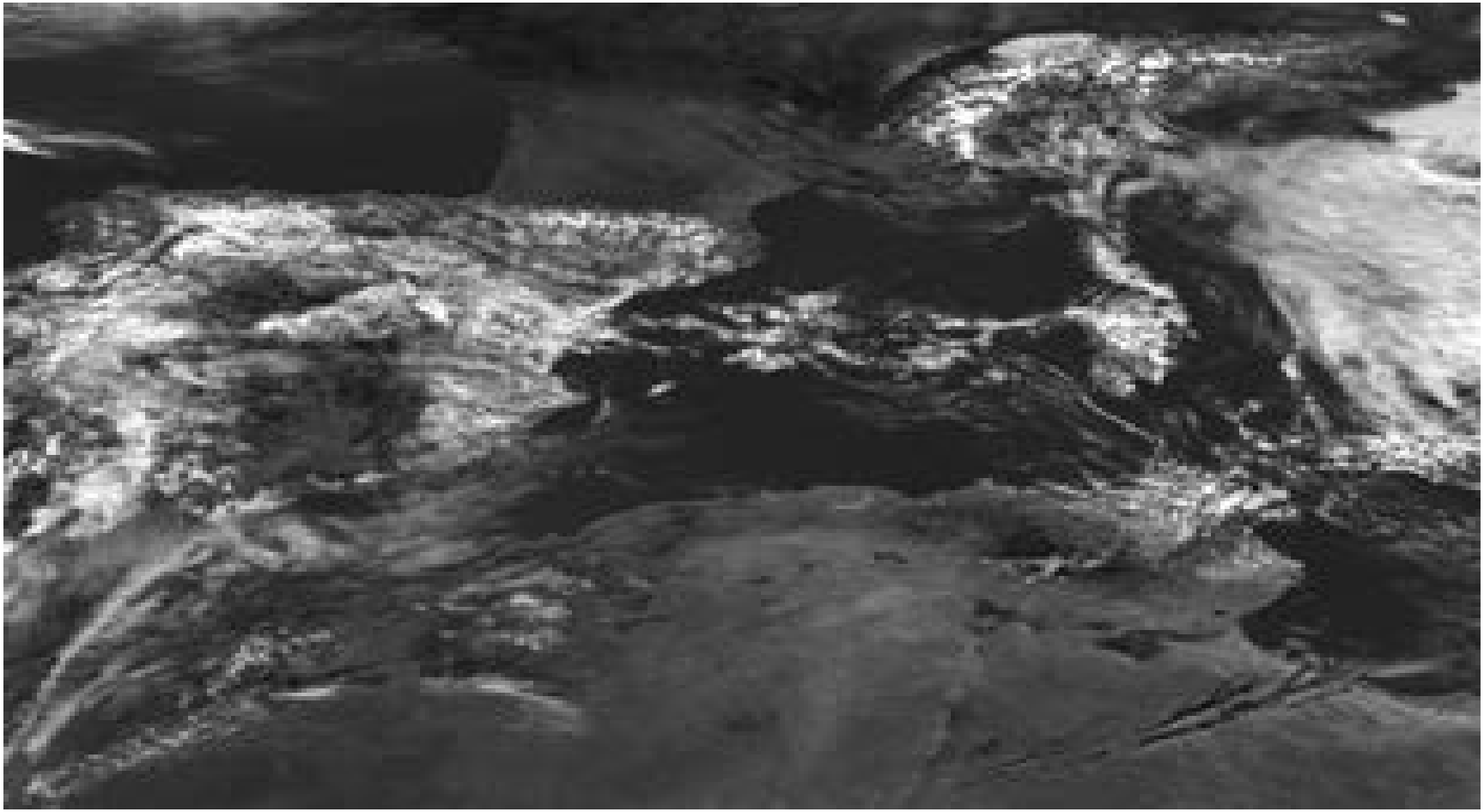


Figure: Cloudindex (date: 05 March, 2011 time: 1200 UTC

Explaining Problem 2

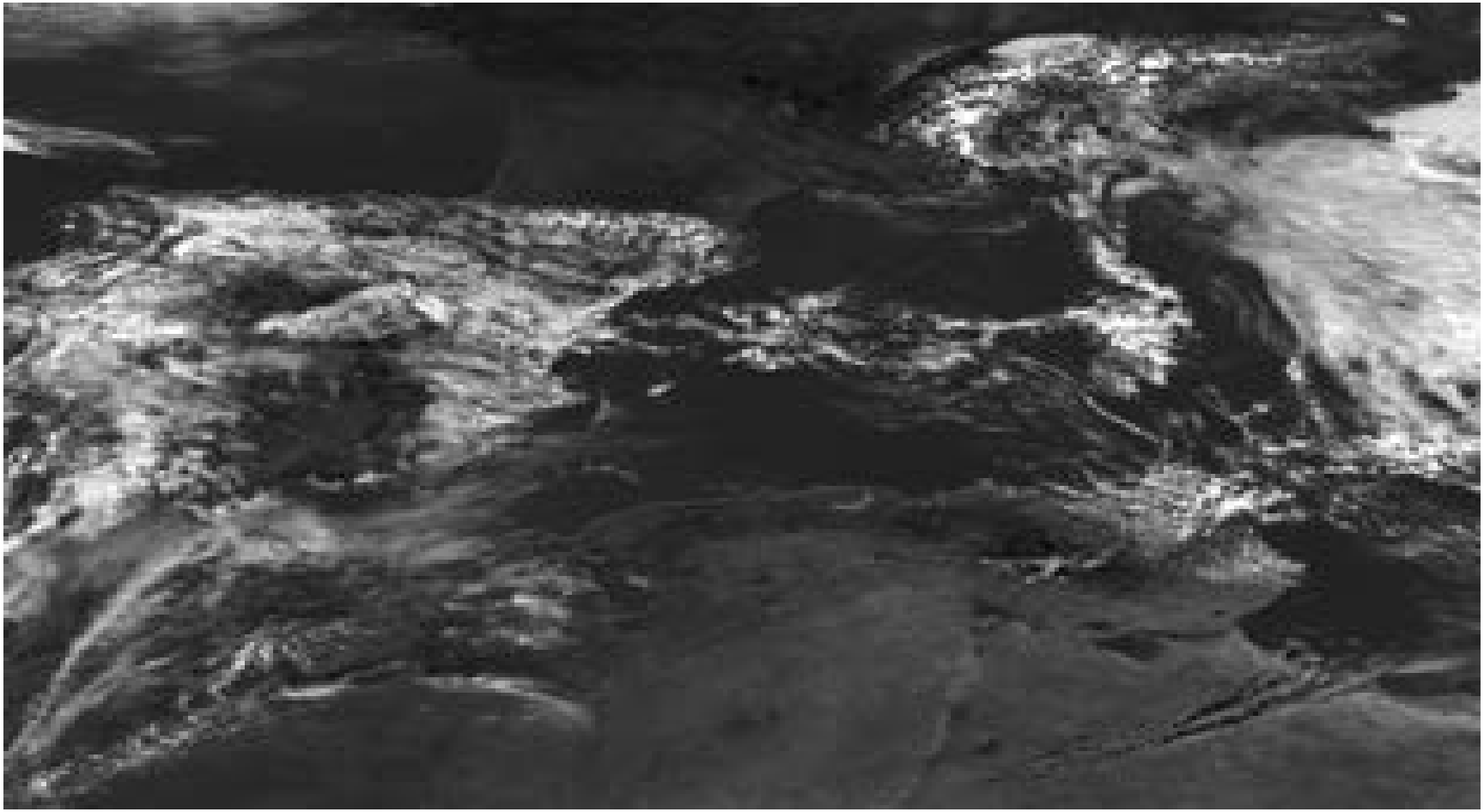


Figure: Cloudindex (date: 05 March, 2011 time: 1215 UTC

Explaining Problem 2

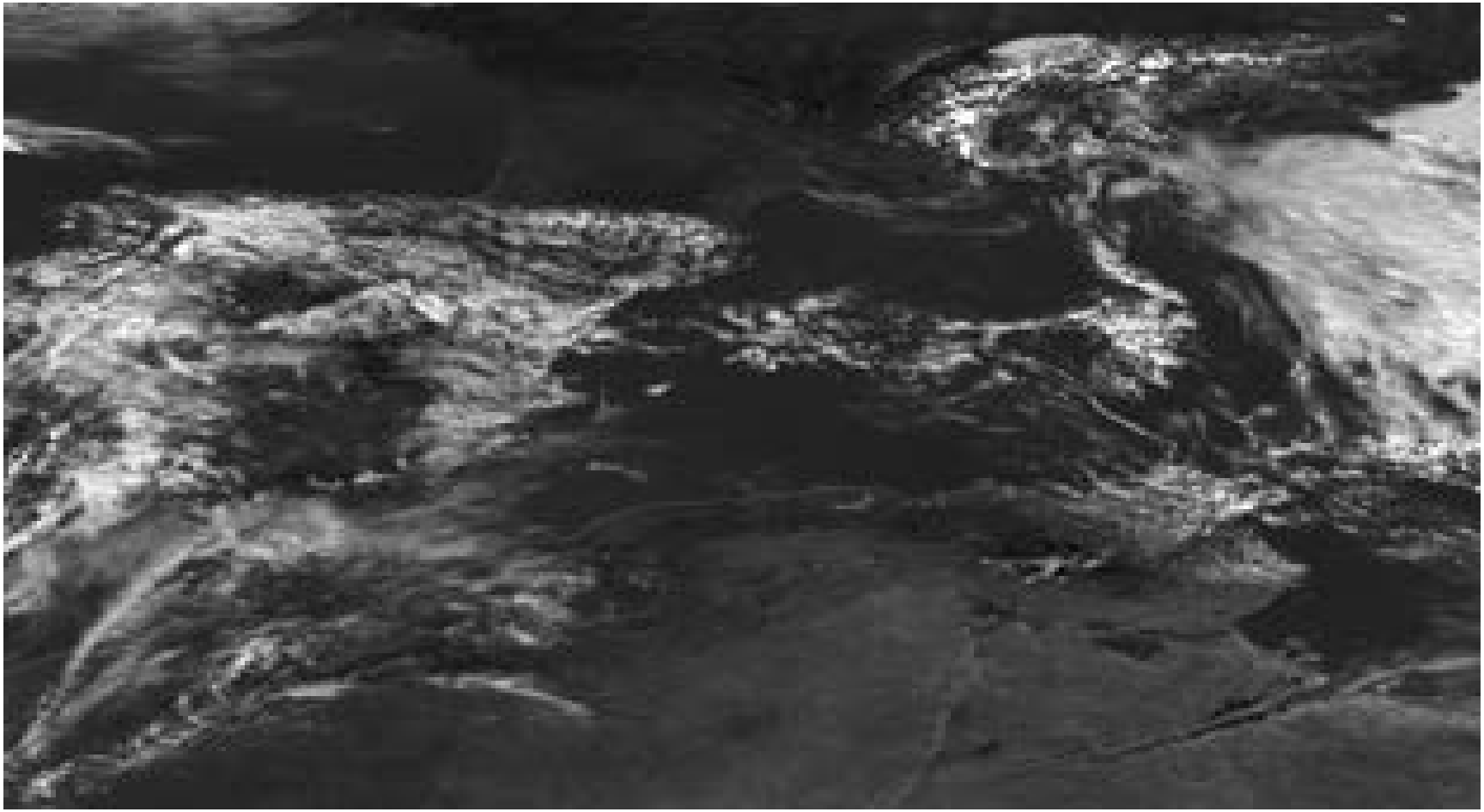


Figure: Cloudindex (date: 05 March, 2011 time: 1230 UTC

Explaining Problem 2

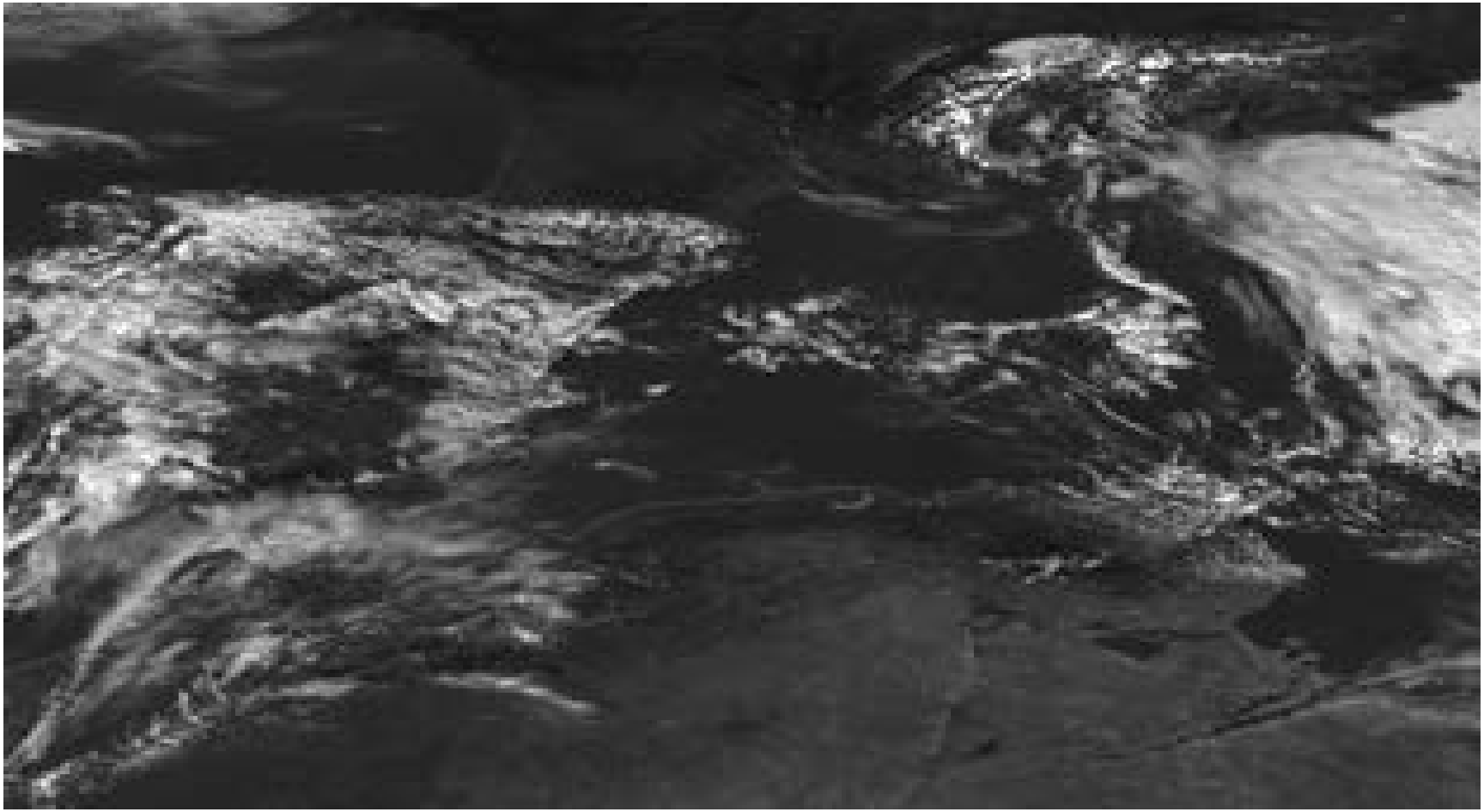


Figure: Cloudindex (date: 05 March, 2011 time: 1245 UTC

Identifying the problems

Problem 3: Albedo calculation over long period

- Ground albedo is usually calculated for each time slot (quarter hourly) over a complete month
- For this calculation, it is assumed that solar elevation and solar azimuth for each slot remains the same throughout the month
- However, during Spring and Fall seasons, solar elevation changes rapidly
- So, during these seasons, ground albedo calculation over 30 days may be inappropriate

Summer Solstice
Spring and Fall Equinox
Winter Solstice

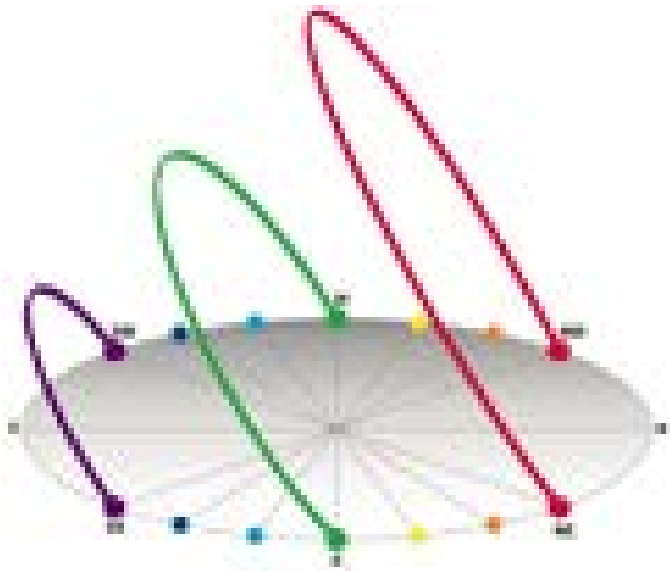


Figure: Seasonality of solar elevation
[Image courtesy: 2012 sunmooncalendar.com]

Proposed solutions

1. Removing images that are either corrupted or have strange artifacts
2. For Spring and Fall seasons, calculating albedo for 10-days instead of 30-days as before; also, grouping days with similar issues on reflectivity for ground albedo calculation
3. For completely missing days, the timeseries is computed from the previous and the next day.

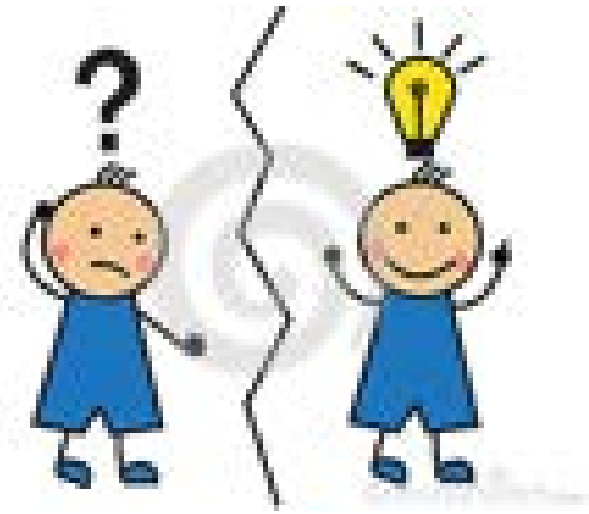
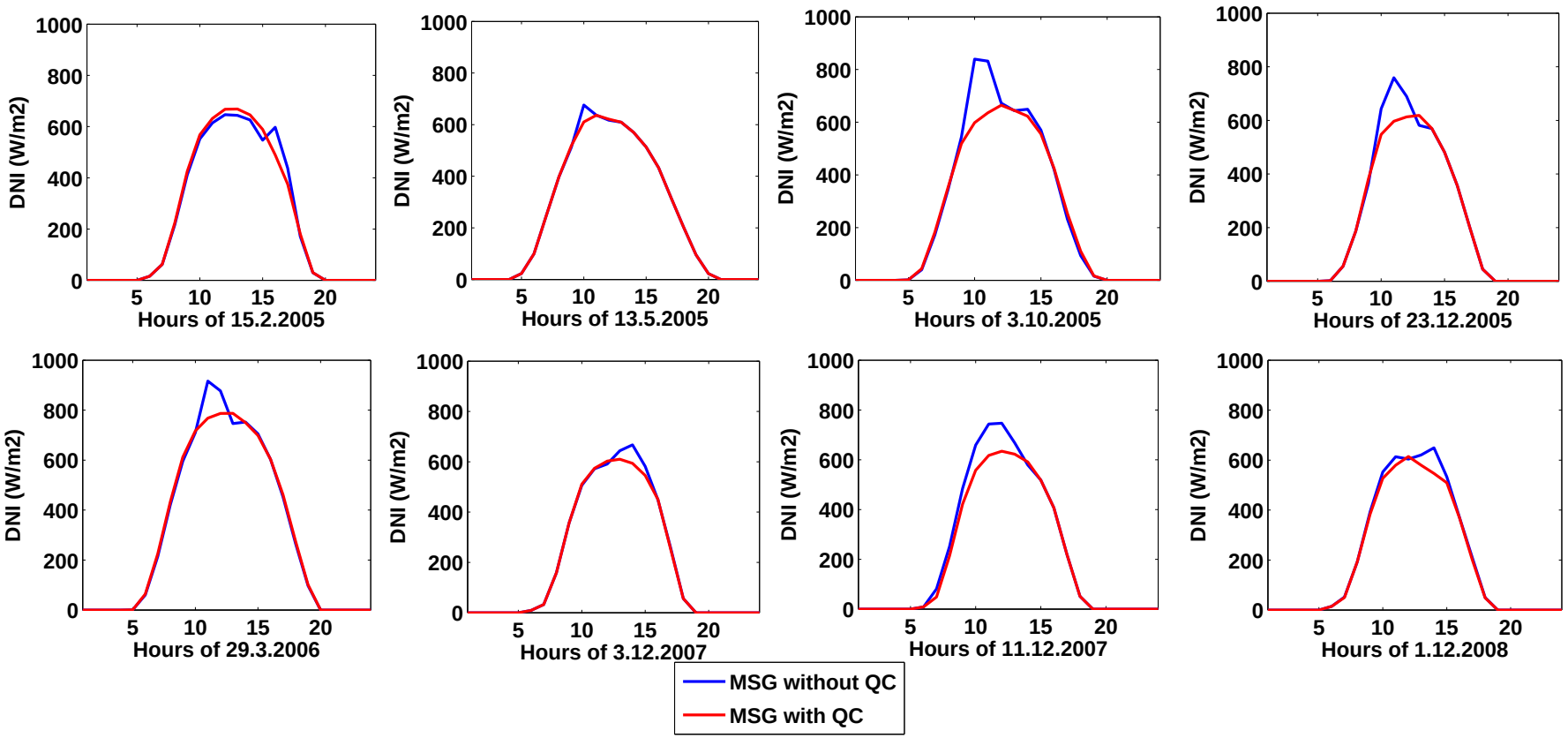


Figure: Image courtesy: dreamstime

Note: Spring (February, March, April) and Fall (August, September, October) months are chosen from issues in timeseries, not from usual classifications.

Days with strange shapes



Estimation of improvement

The improvement in timeseries upon quality control can be estimated by

- comparing MFG and MSG for the overlapping year 2005
- comparing MSG without QC and MSG with QC

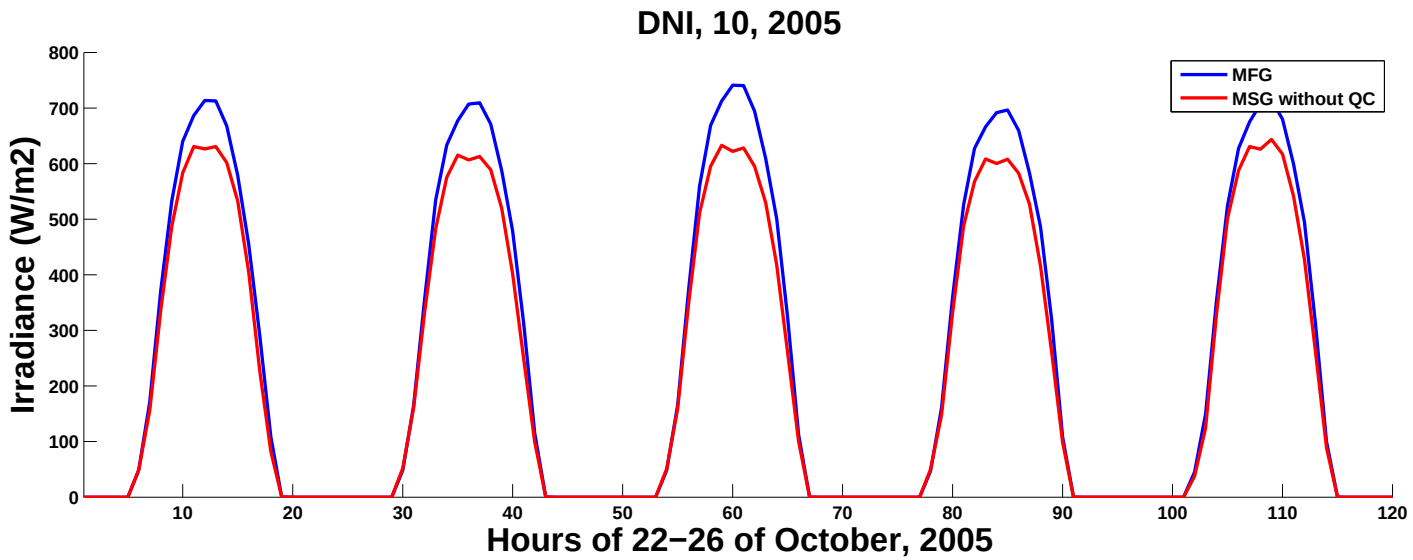
Since CSP timeseries are closely related to DNI, some examples may show DNI analysis instead of CSP

Estimation of improvement

Comparing timeseries from MFG and MSG for the overlapping year 2005

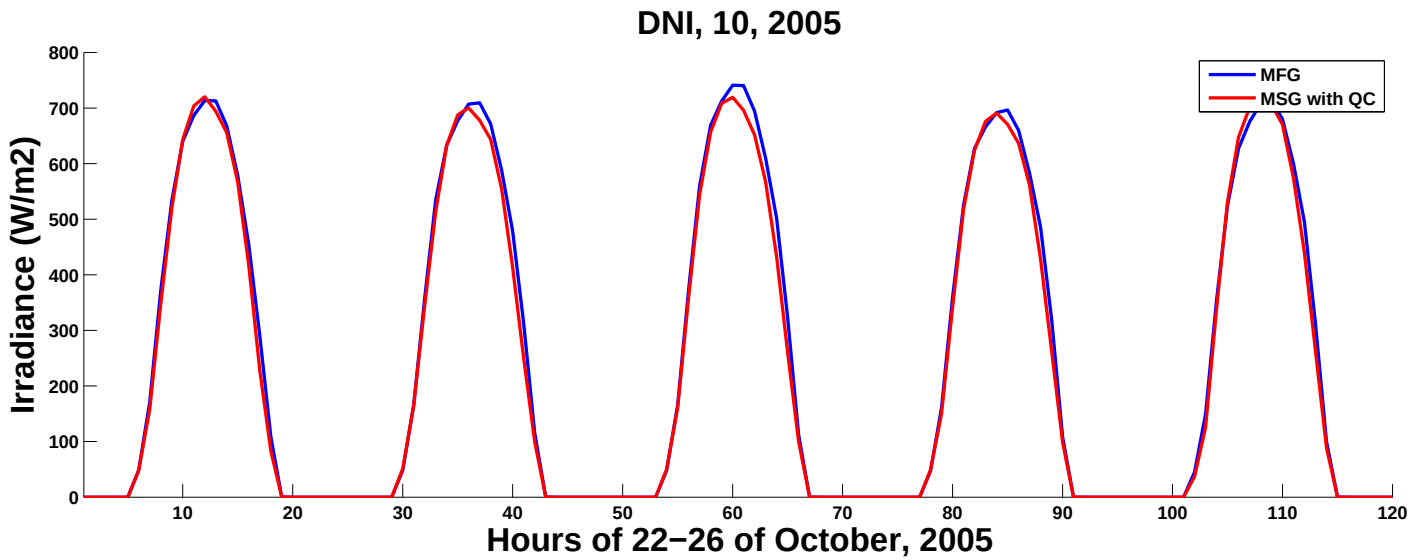
Comparison with MFG

The overlapping year 2005 was compared with MFG.
For MSG without quality control or recalculation of albedo:



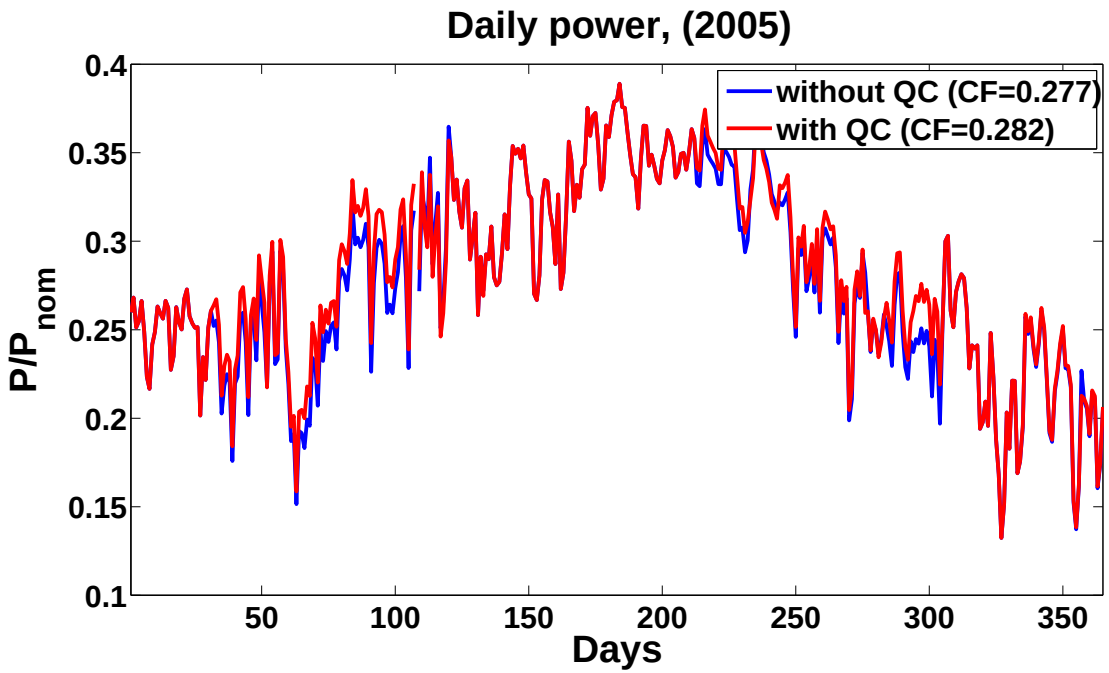
Comparison with MFG

The overlapping year 2005 was compared with MFG.
For MSG with quality control and recalculation of albedo:



Daily timeseries

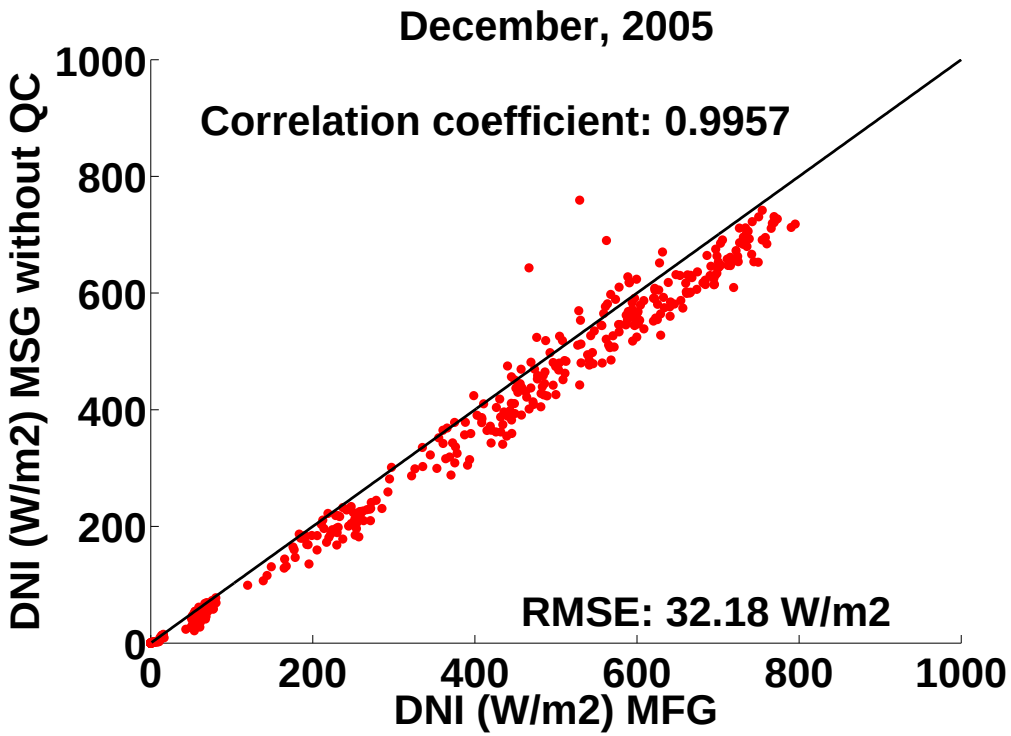
While Summer and Winter months were checked only for corrupted images, Spring and Fall months were corrected for both image quality and albedo recalculation:



Steeper slope (causing rapidly changing albedo) during Spring and Fall requires albedo calculation over smaller period instead of usual 30-days.

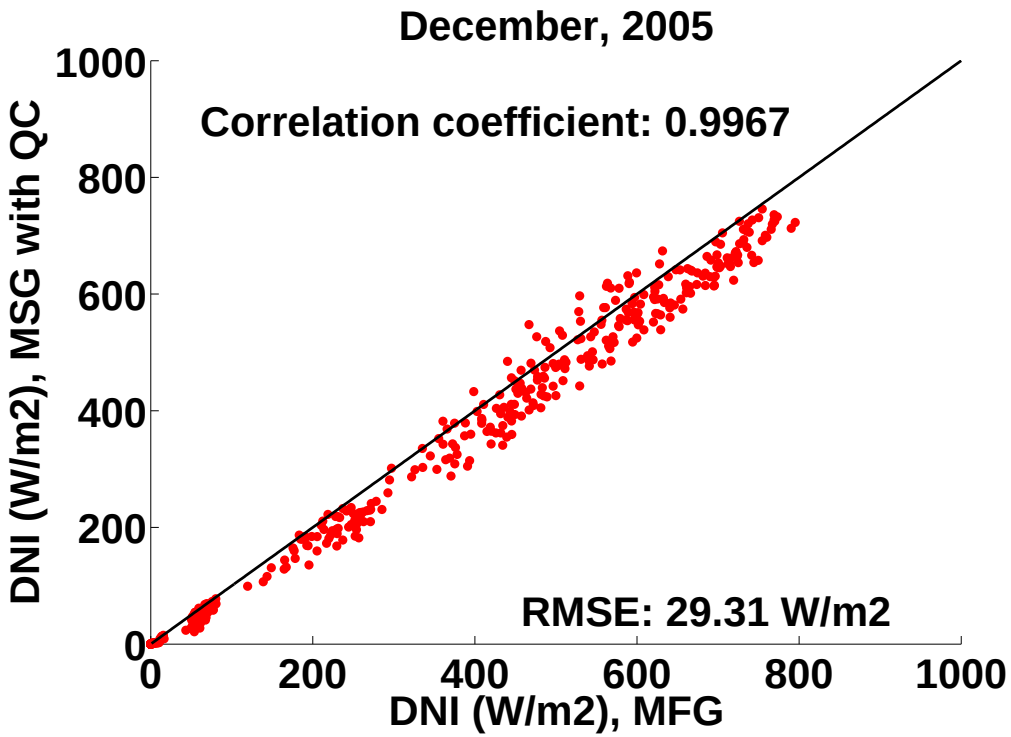
Comparison with MFG

For Winter and Summer months, correlation analysis shows:



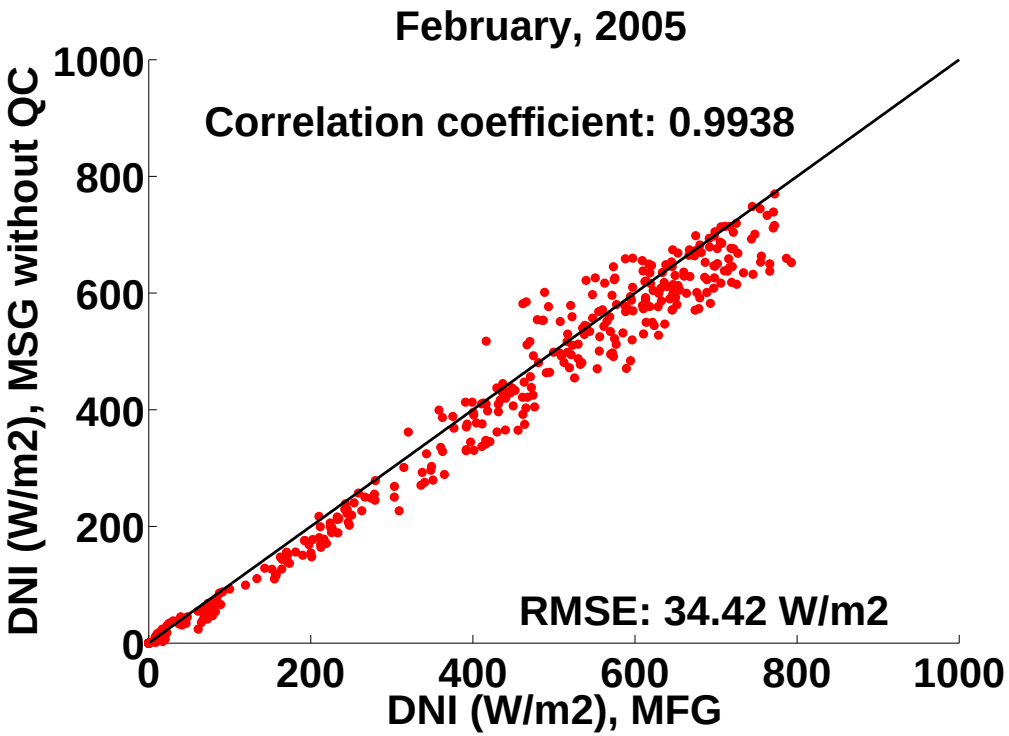
Comparison with MFG

Upon quality control, outliers in correlation analysis were removed:



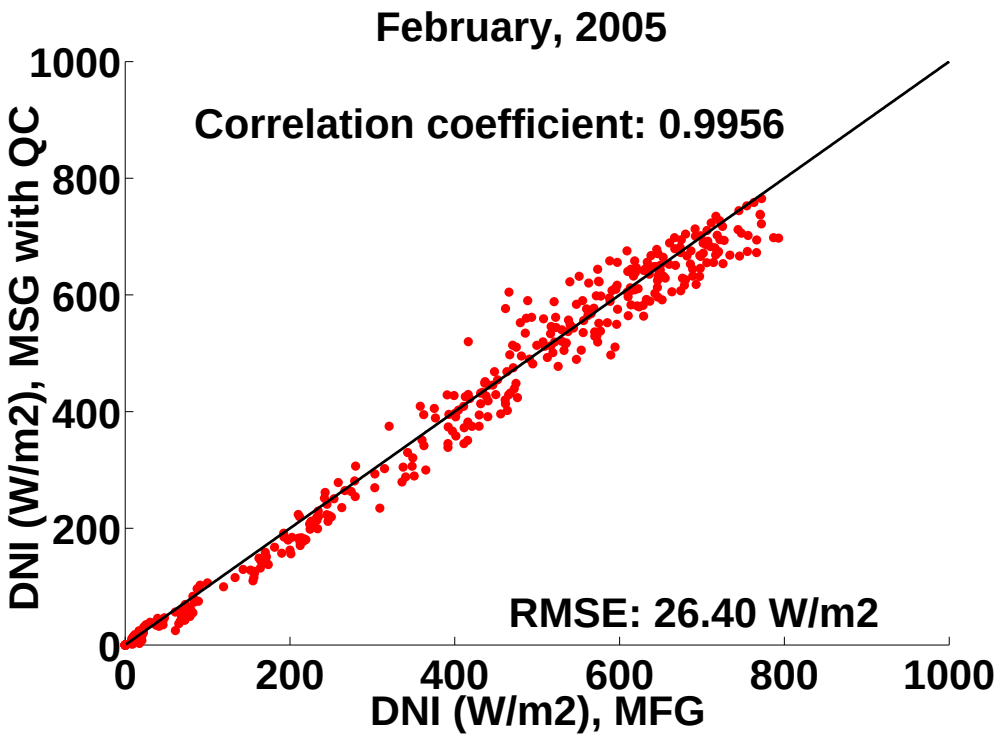
Comparison with MFG

For Spring and Fall months, both quality control and albedo recalculation were done:

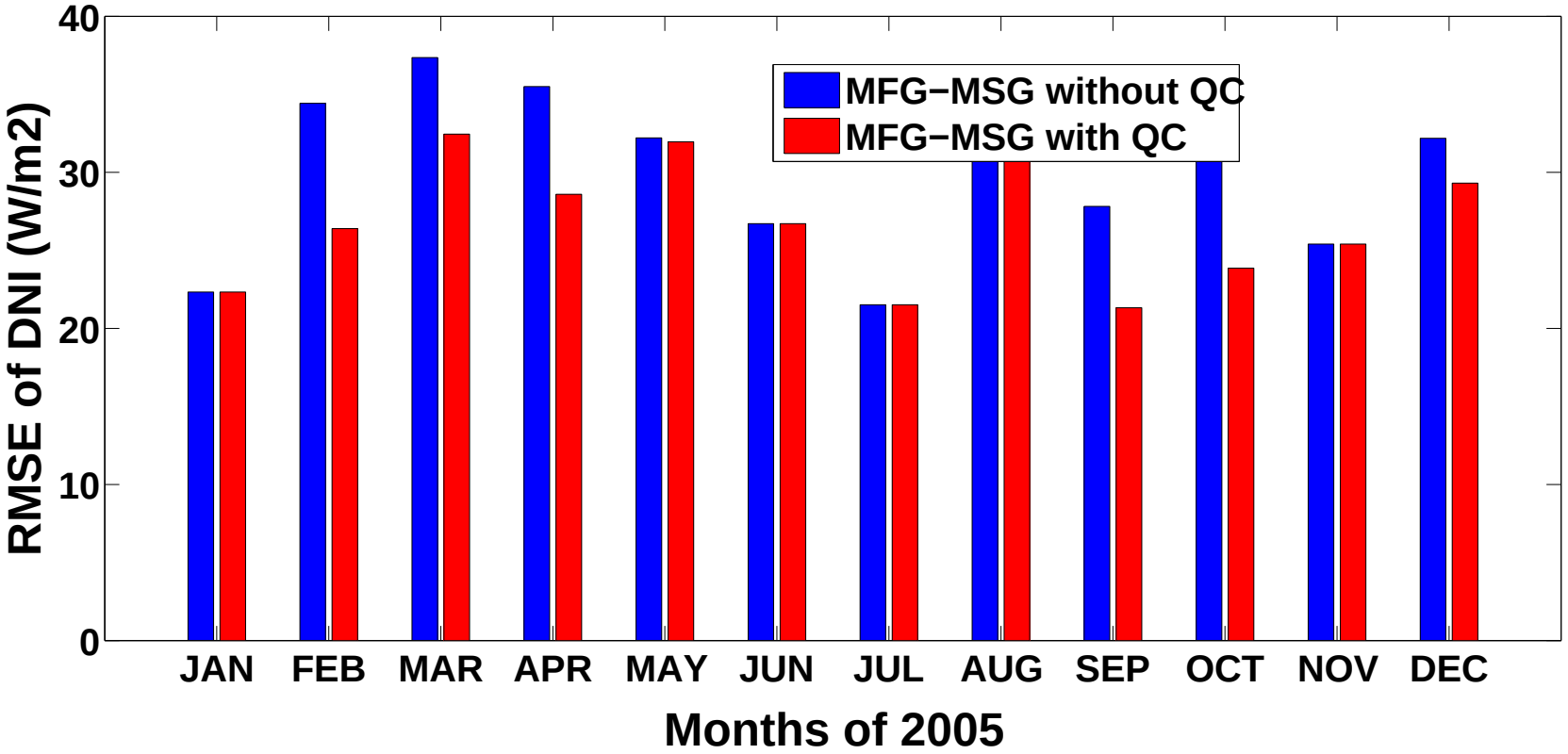


Comparison with MFG

Increase in correlation coefficient for these seasons:



RMSE estimation

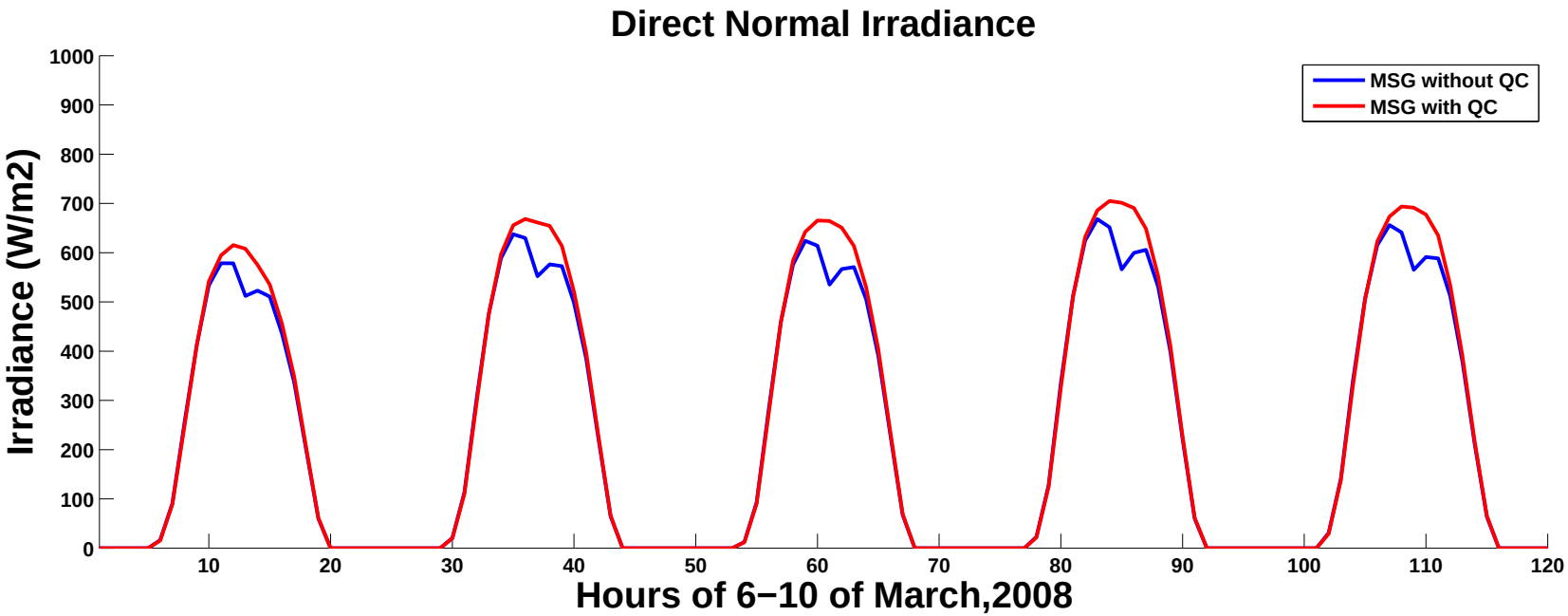


Estimation of improvement

Comparing timeseries from MSG without QC and MSG with QC

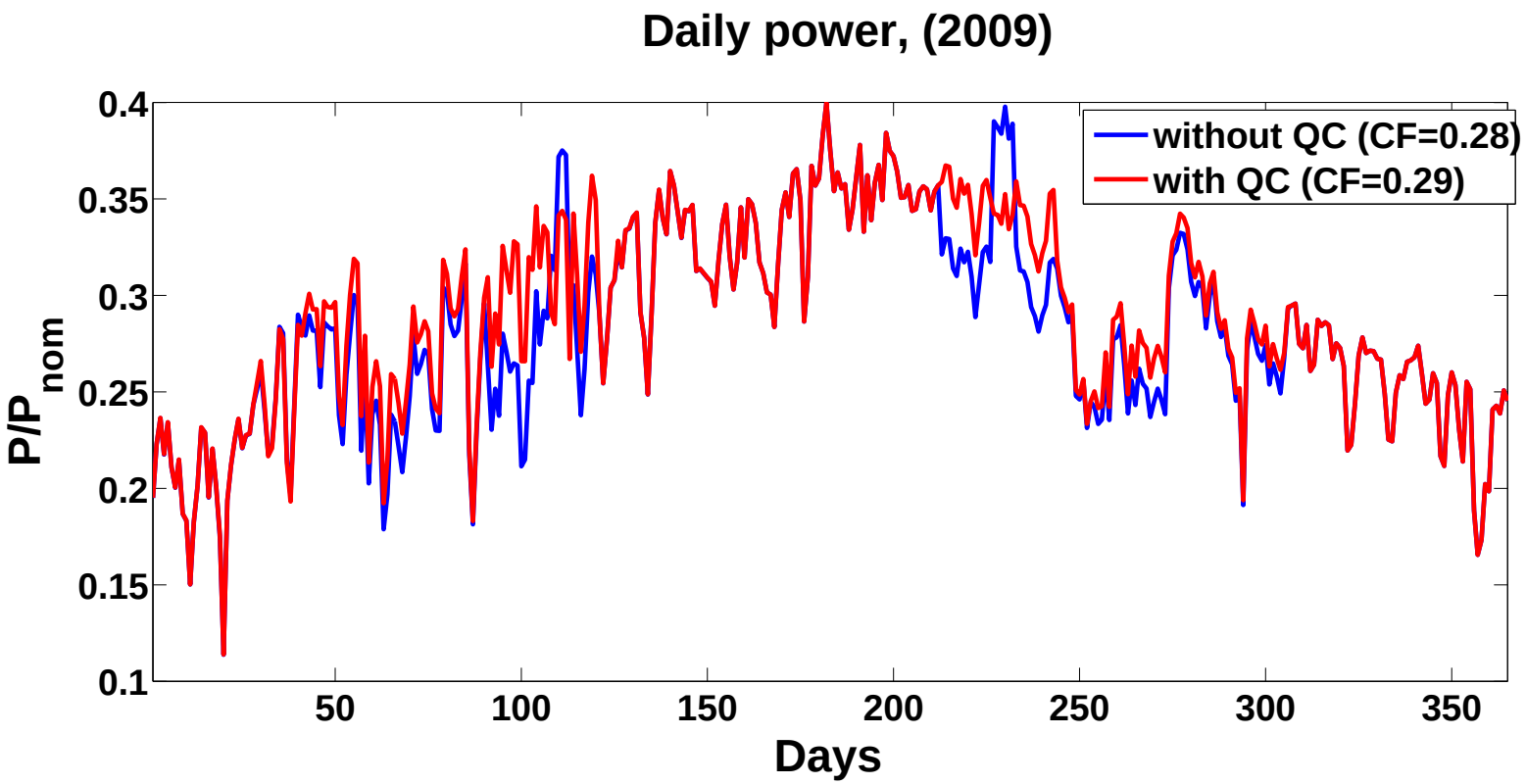
Improvement on QC

Changes in timeseries upon QC and recalculation of albedo with shorter period:



Impact on daily values

Upon QC, the annual curve gets much smoother with overall increase in production:



Capacity factor

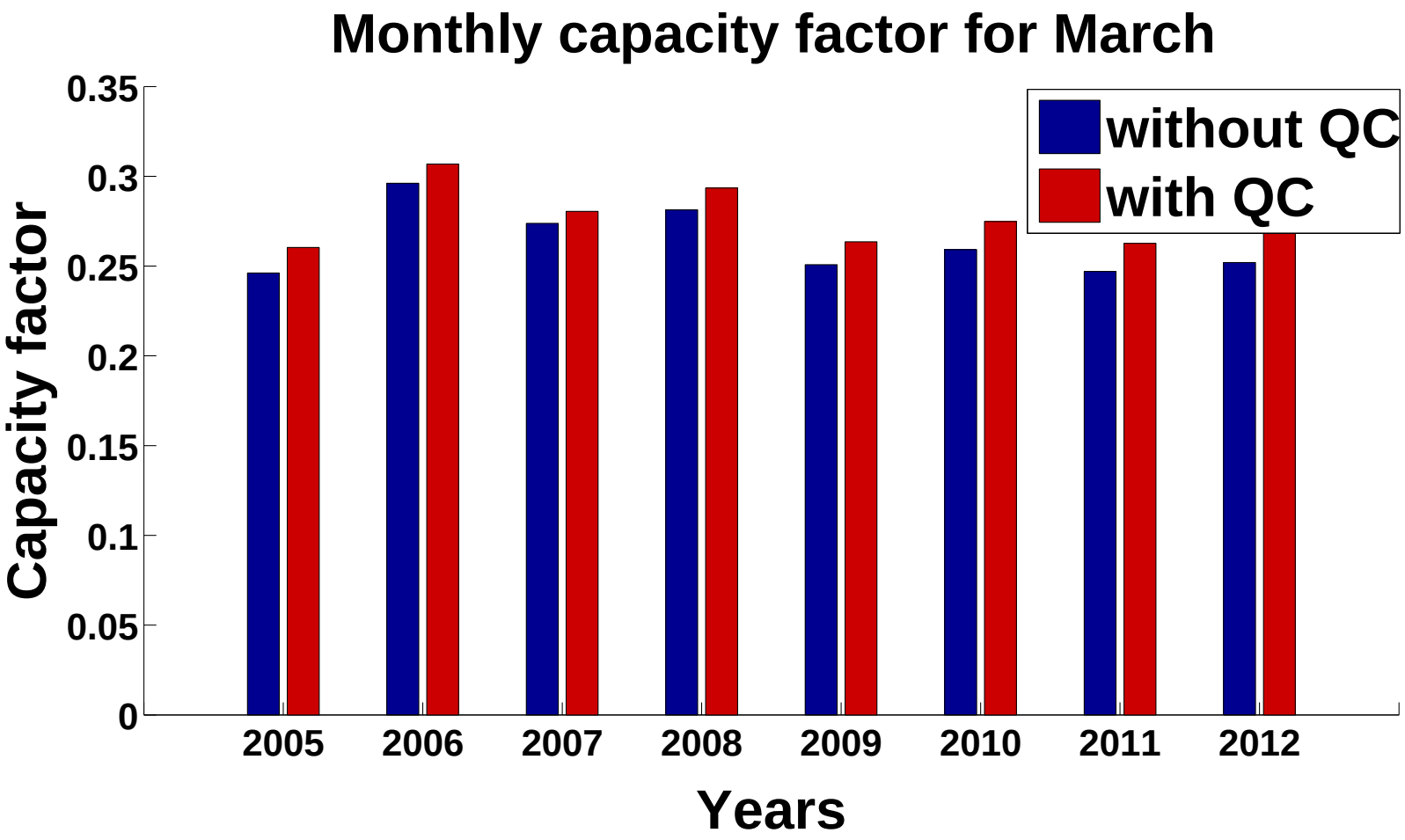
Definition of Capacity factor (CF)

The net capacity factor of a power plant is the ratio of its actual output over a period of time, to its potential output if it were possible for it to operate at full nameplate capacity continuously over the same period of time.

Analysis of Capacity factor shows:

- Annual capacity factor has increased for all years
- While for Winter and Summer months, CF has increased only 0.17%, it has increased 4.02% for Spring and Fall months
- Overall, annual capacity factor has increased around 2.06%

Estimation of Capacity factors



Summary

- The CSP timeseries for Sahara had some strange features, specially during Spring and Fall seasons
- To remove these effects, the defective images were discarded for calculation and ground albedo was recalculated with 10 days for Spring and Fall months
- The newly formed timeseries upon QC was compared with reference timeseries from MFG during 2005. The improvement was also estimated with respect to the timeseries without QC
- They show overall improvement with increased annual production for all years. The improvement is more prominent for Spring and Fall compared to the other months.

Outlook

Further analysis will include

- CSP distribution with high capacity: finding the best locations
- Sensitivity study of PV module configurations
- Some additional statistical analysis of delivered timeseries

Thank You for your Attention!

Questions?