

Mapping global cloudiness from visible MODIS imagery: some new results

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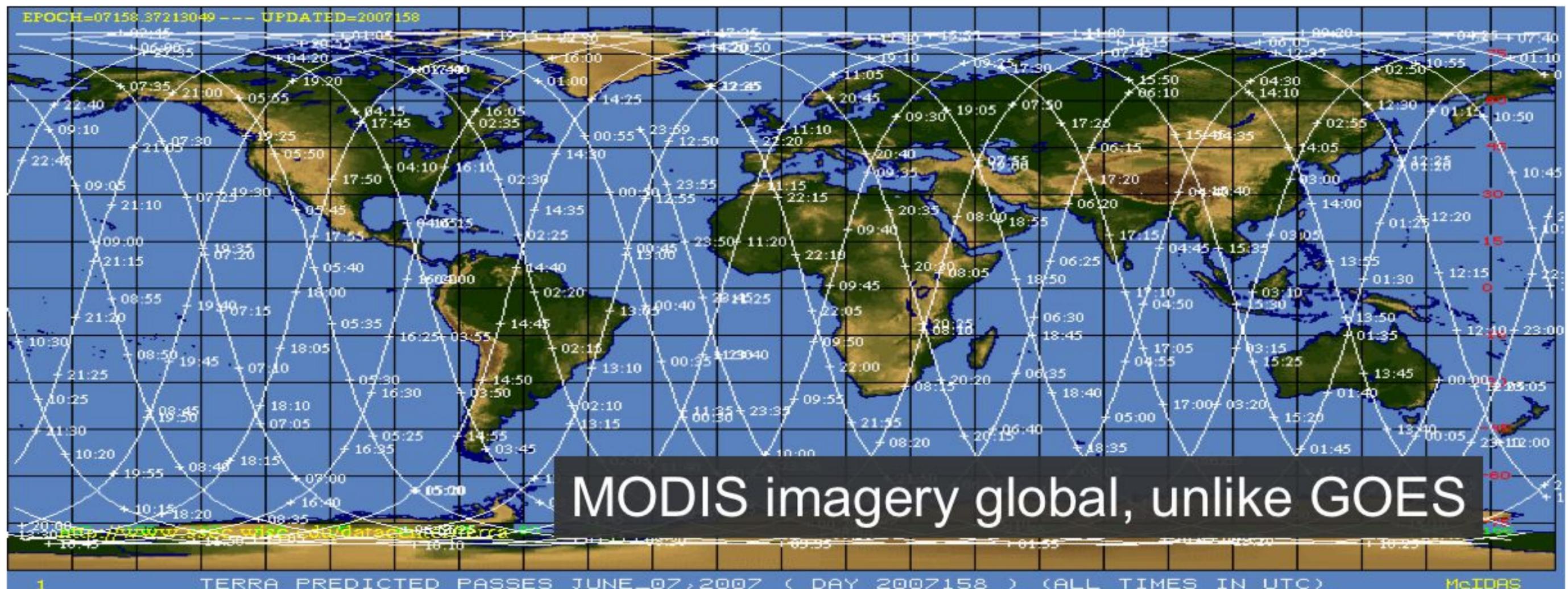
(work done by numerous students over past 5+ years including Abdul Dominguez, Rahama Beida, Rob Nelson (Hollings), Tracey Dorian (REU), John Mejia, Raquel Ozozco, Jose Galvez and others)

Potential applications of high-resolution cloud climatologies

- Aid in downscaling climate and weather forecasts
- Compare with numerical simulations of cloudiness to detect systematic deficiencies in high resolution NWP models.
- Create more detailed maps of solar energy potential
- Help with ecological studies that link species distributions to climate
- Aid weather forecasters by increasing their understanding of local climate and of different processes responsible for the formation of mean cloudiness patterns

MODIS Imagery from Terra and Aqua satellites

- **M**oderate Resolution **I**maging **S**pectroradiometer
- Terra (AM) and Aqua (PM) satellites, ~3 hours apart, equator crossing at 1030 and 1330 LT
- 36 Spectral Bands (0.405-14.385 μ m)
- Swath width of 2,330km with **250m spatial resolution** at visible wavelength.
- $\pm 55^\circ$ Scanning Pattern, altitude 705 km
- Note that scan width means imagery can be ~ 40 min on either side of satellite nadir time (thus 10:30 LT imagery can be from 9:50 LT to 11:10 LT at Equator).





Subsets

This page contains a number of image subsets that are automatically generated in near-real-time for various applications users. Most subsets are available as true-color images. Some additional band combinations may be available for specific applications. Geographic areas can be selected from the maps or from the list below. For each geographic area the archive imagery is available online.

Subsets for a few projects can also be accessed through these specific URLs:

<http://rapidfire.sci.gsfc.nasa.gov/aeronet>

<http://rapidfire.sci.gsfc.nasa.gov/fas>

<http://rapidfire.sci.gsfc.nasa.gov/servir>

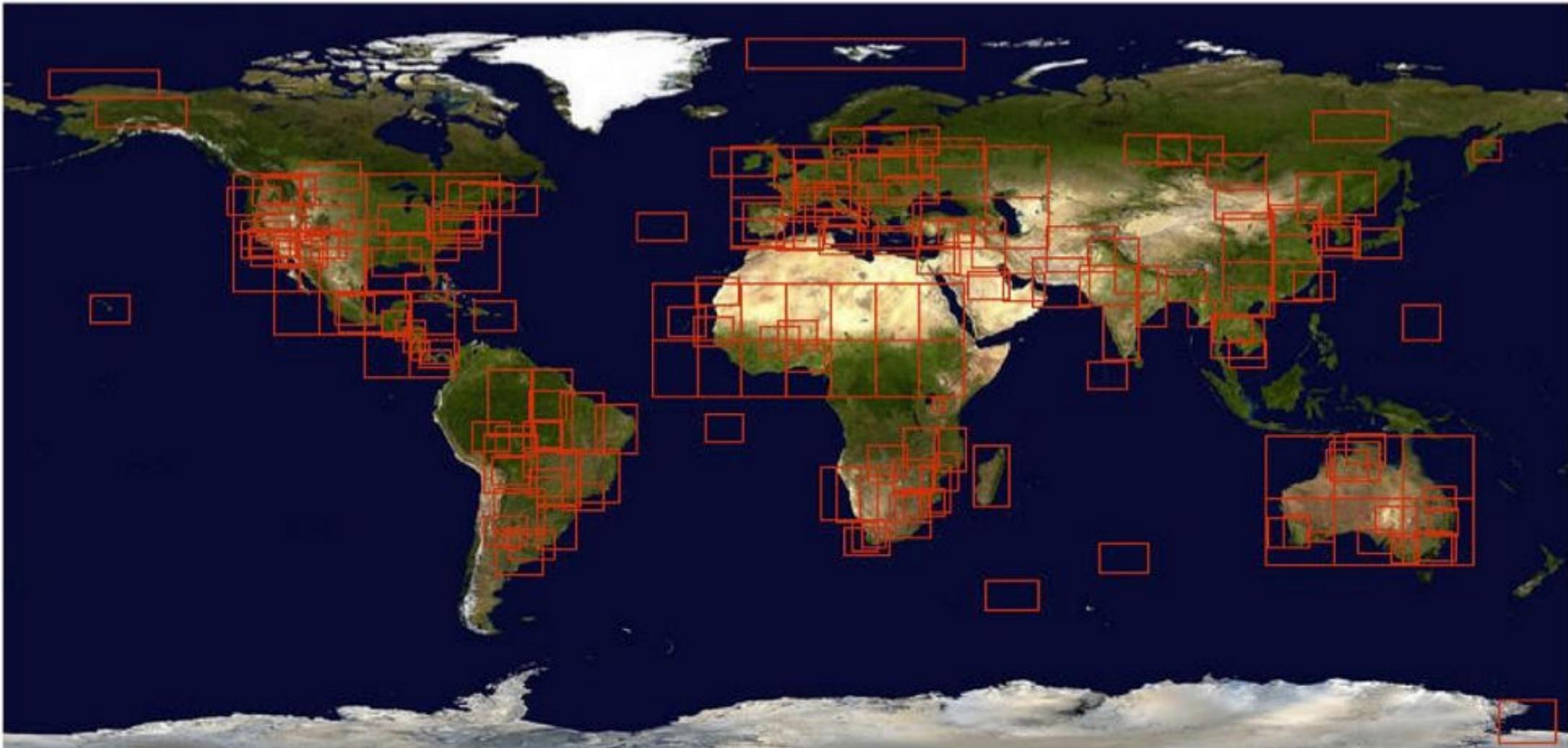
<http://rapidfire.sci.gsfc.nasa.gov/jason>

<http://rapidfire.sci.gsfc.nasa.gov/uae>

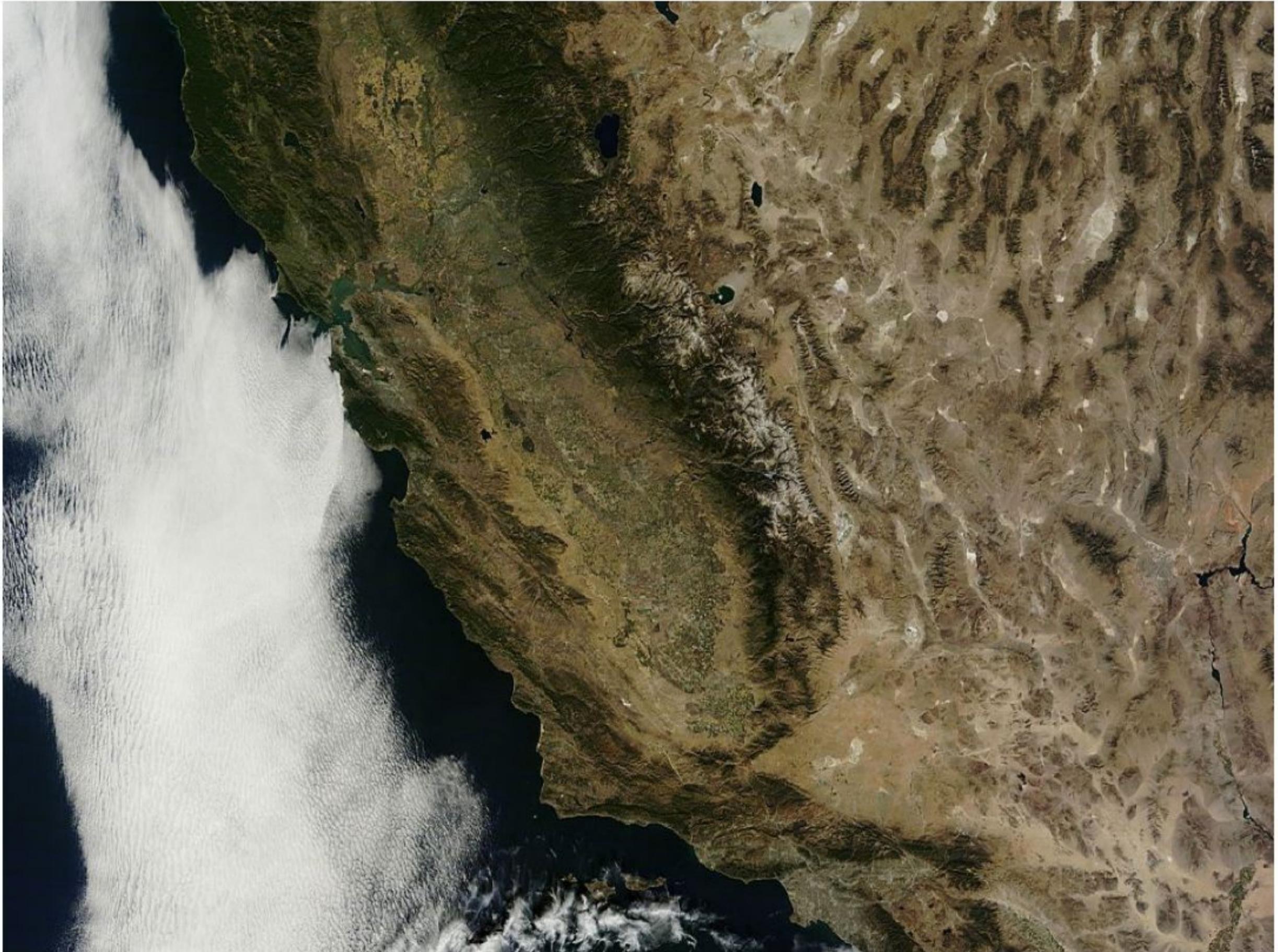
Source of MODIS imagery...

Select a subset:

(click on the map or pick from the list below)



Example MODIS “true color” image...



History...

Original motivation for working with MODIS imagery was to help identify best locations for pilot balloon stations (most cloud-free) for our network in Latin America..

We also wanted to help explain distribution of very moist forest in Bolivia for collaborators (botanists) who were helping to make our meteorological measurements of a low-level jet.

Why work with MODIS visible imagery?

1. Visible imagery has better spatial resolution (resolves better topography-cloud relations over land).
2. MODIS imagery is very well-navigated compared with GOES imagery, thus more suitable for time-averaging.

~ 1 year mean MODIS composite (AM data)
patterns resemble precipitation patterns, but are not the same...
cannot easily infer precipitation from visible imagery

ITCZ - high precip

Stratocumulus
(little precip)



How do we go about generating such cloud climatologies?

HOW ALGORITHM WORKS

Download "True color" MODIS imagery from NASA site



Convert to gray scale

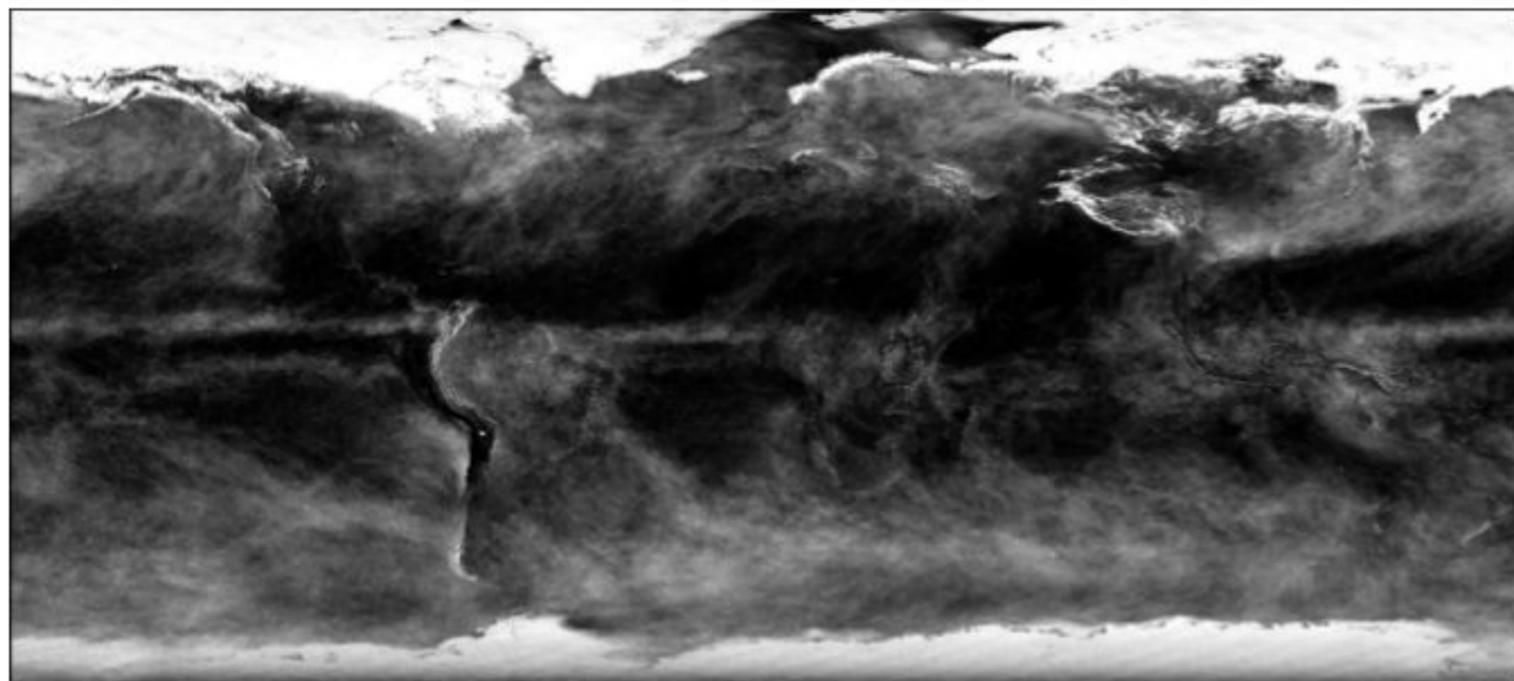
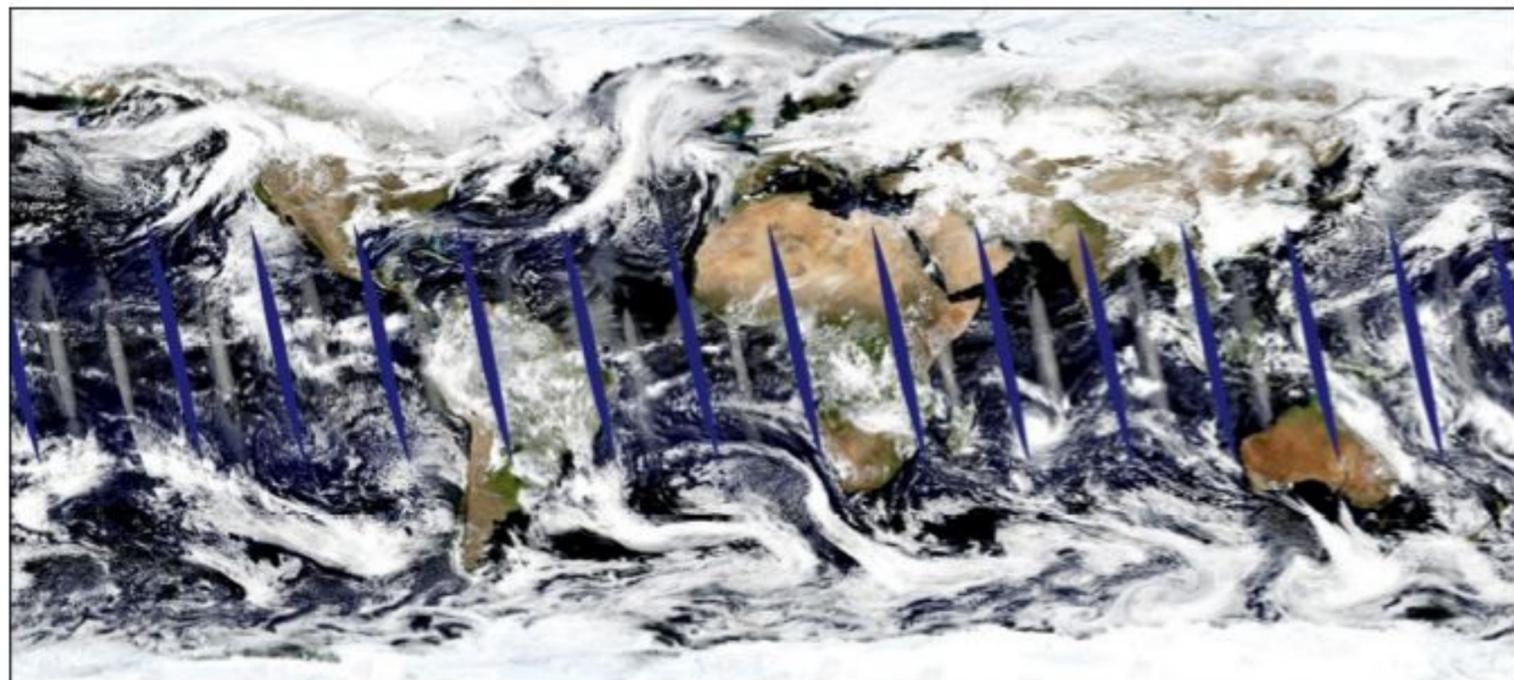


← Cloudy pixels extracted with a particular threshold (0-255) (algorithm designates cloudy or not cloudy based on pixel brightness values compared to threshold)



← Averages over one month to get monthly mean cloudiness

(shown is 5km global mosaic)



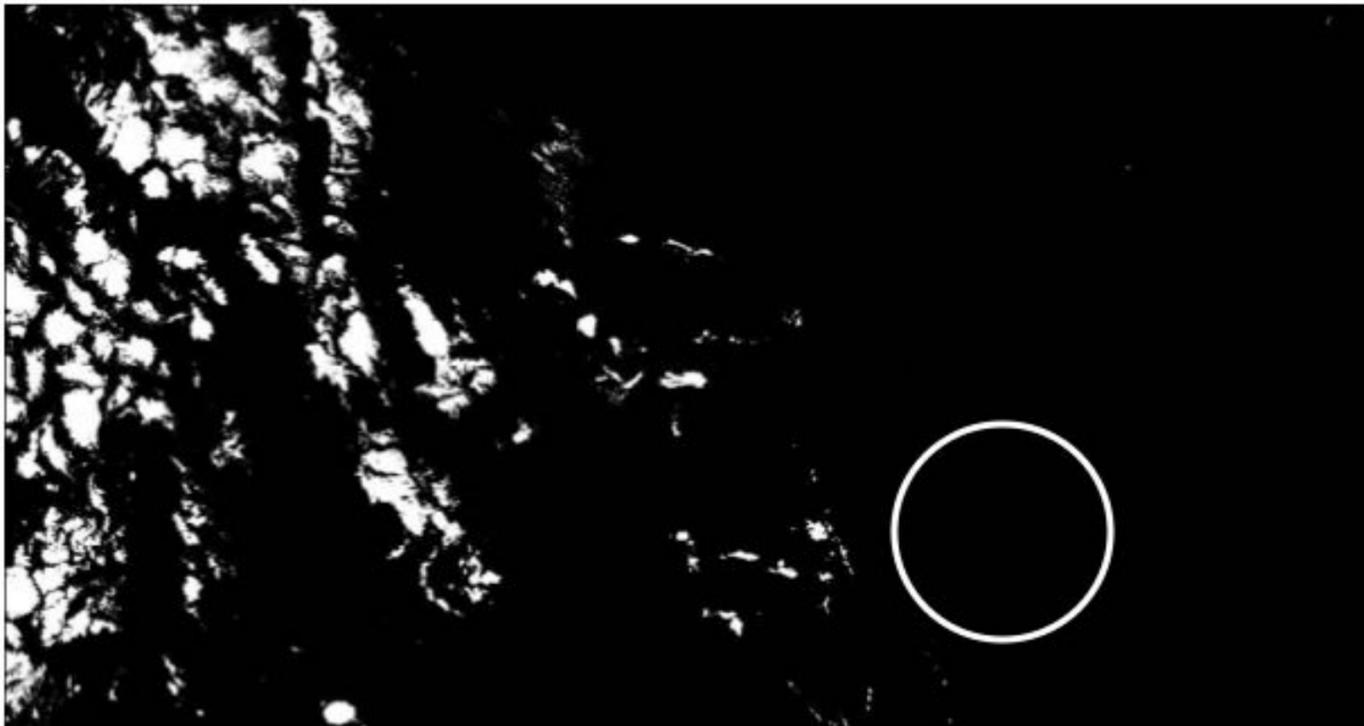
Short mention of related work this past summer
by REU student Tracey Dorian and Hollings
student Rob Nelson

Different thresholds yield different cloud amounts... (both disadvantage and advantage)

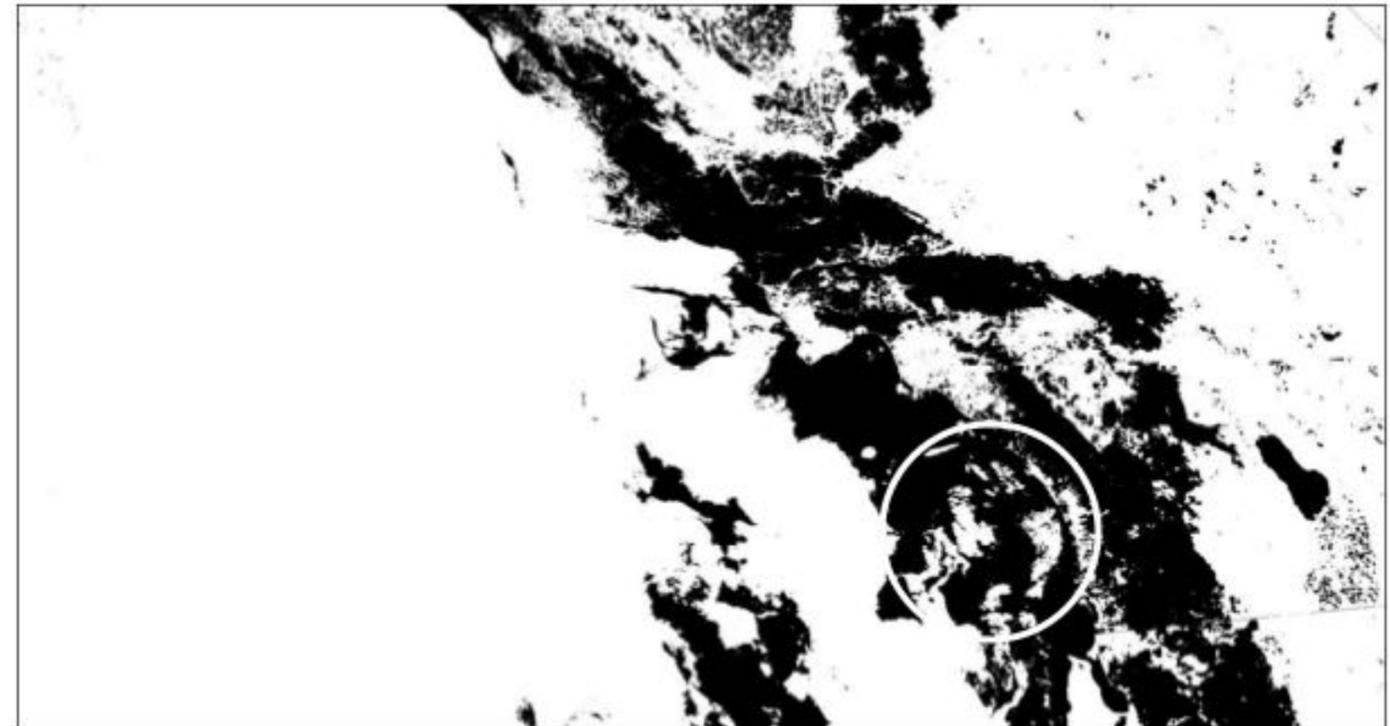
Original true color image



160

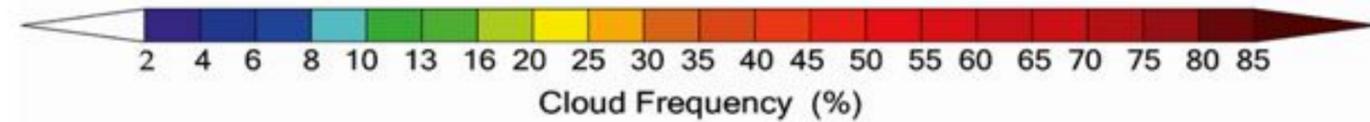


215

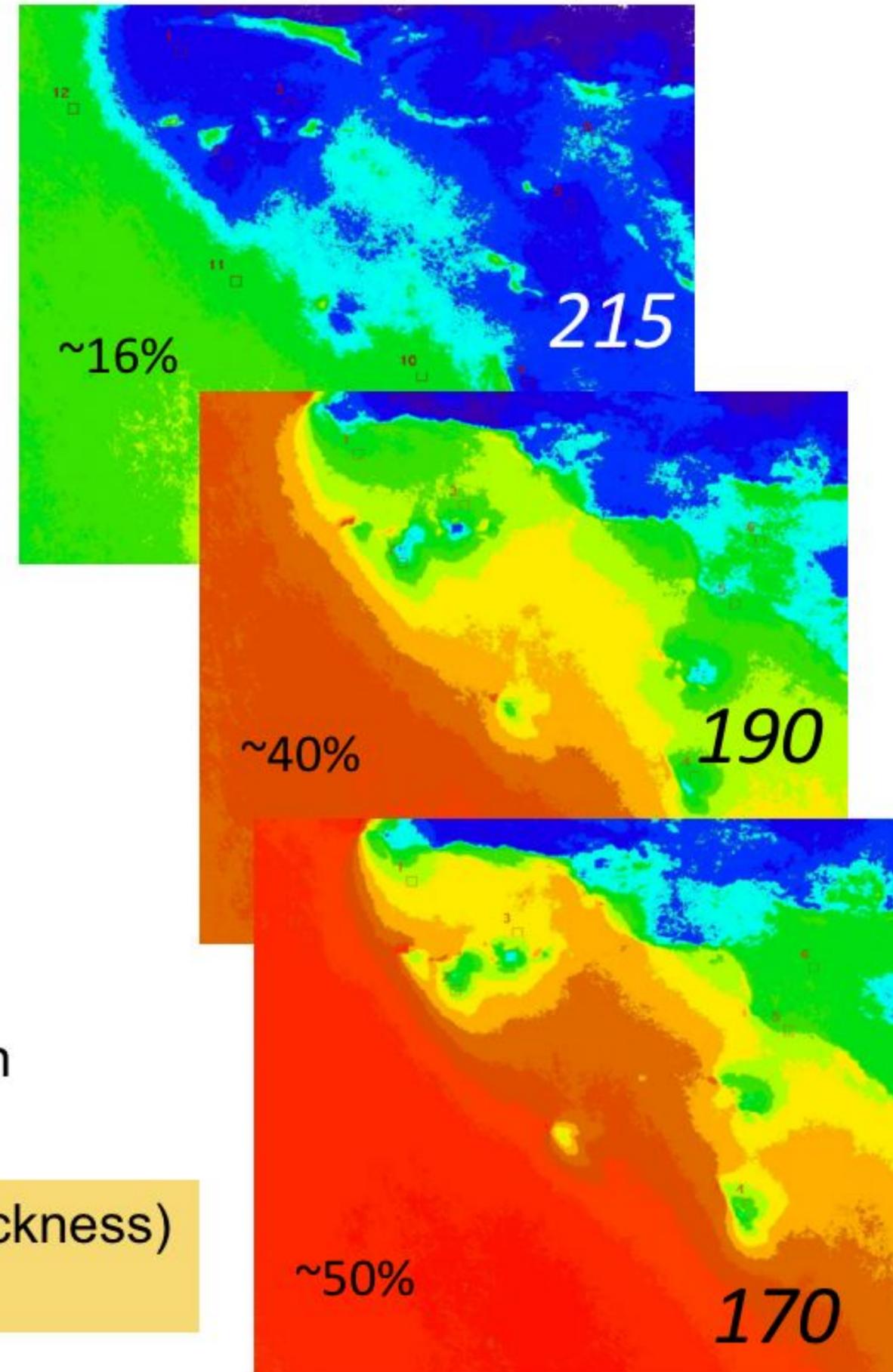


120

REU student Tracey Dorian's work this past summer...



- Past work – Although cloud climatologies appeared realistic, cloud algorithm with 215 threshold underestimates cloud frequencies, especially over oceans
- OUR GOAL: Understand geographical “behavior” of algorithm and find threshold value for best accuracy
- Increase our confidence in algorithm’s performance
- To do this required subjective estimation of cloudiness for selected pixels and comparison with algorithm output

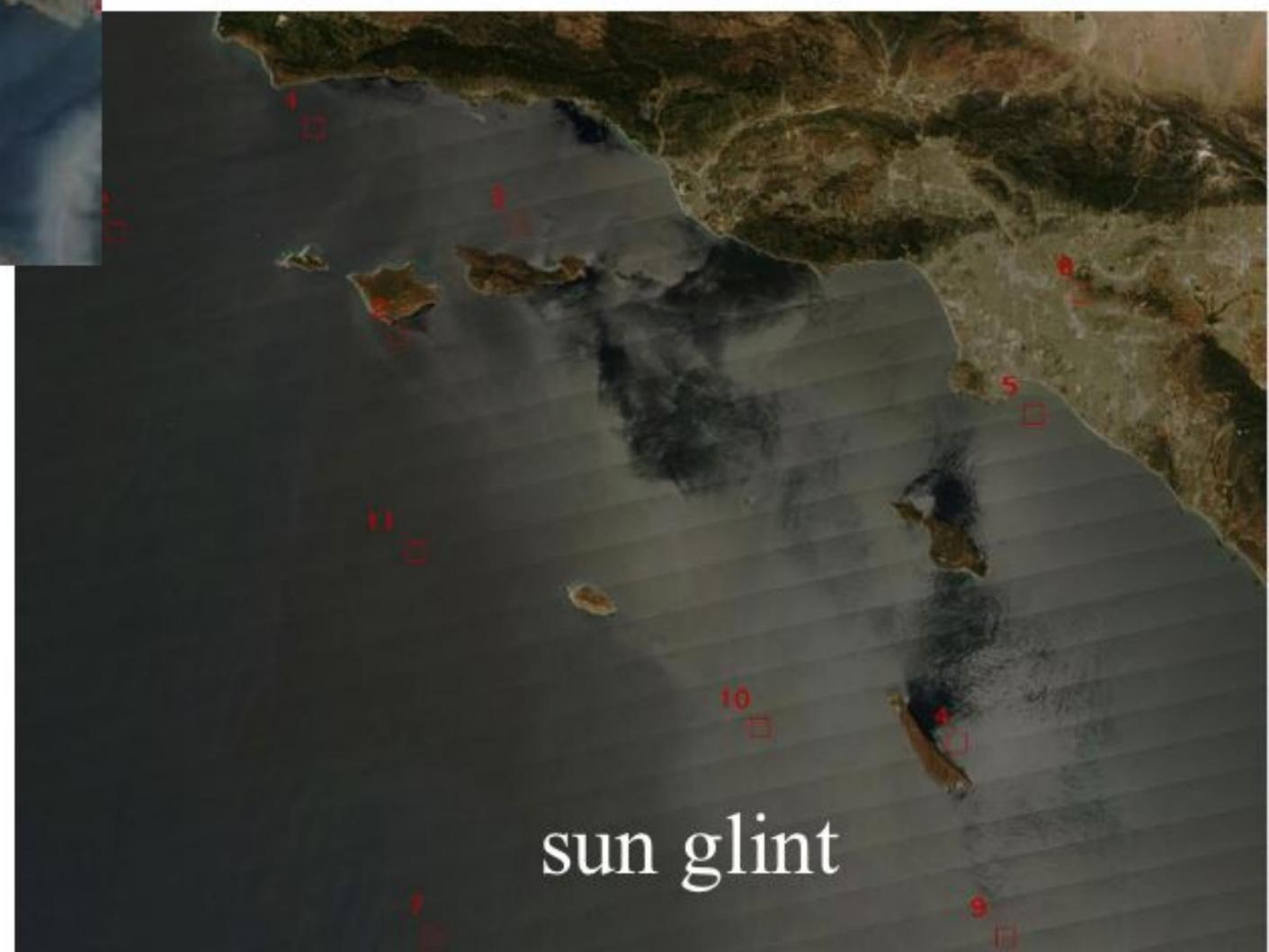


RESULT: you have to decide what brightness (thickness) cloud you want to detect... “your results may vary”

Some problems with with cloud detection using visible imagery



- ice and snow
- sun glint
- salt flats
- dust and smoke
- bright land surfaces
- shadows



Comparison of High Resolution Cloud Climatologies from MODIS Imagery and Mesoscale Models

Robert Nelson
Iowa State University

Our 215 threshold product



NASA Cloud mask product



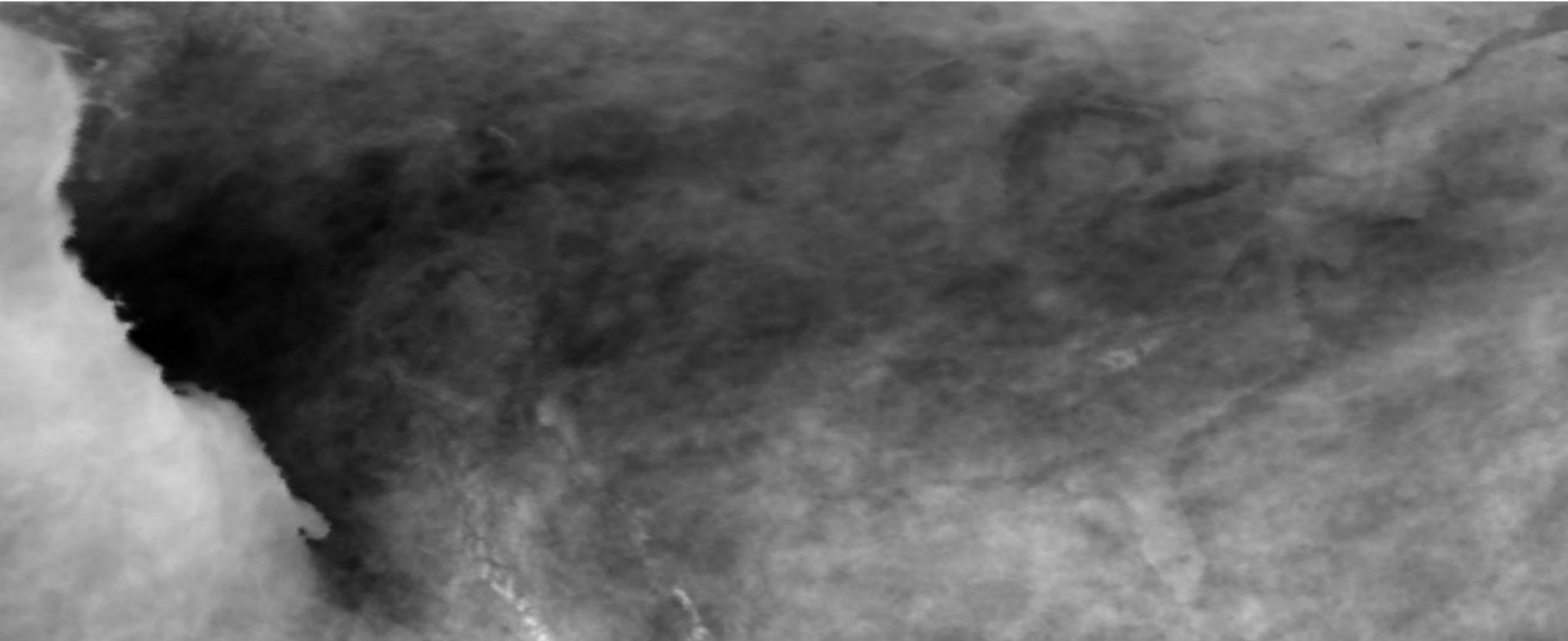
July, August, September 2010 means

Closer view of July-September 2010 cloud mask mean



Reflects too strongly the underlying surface, cities, albedo

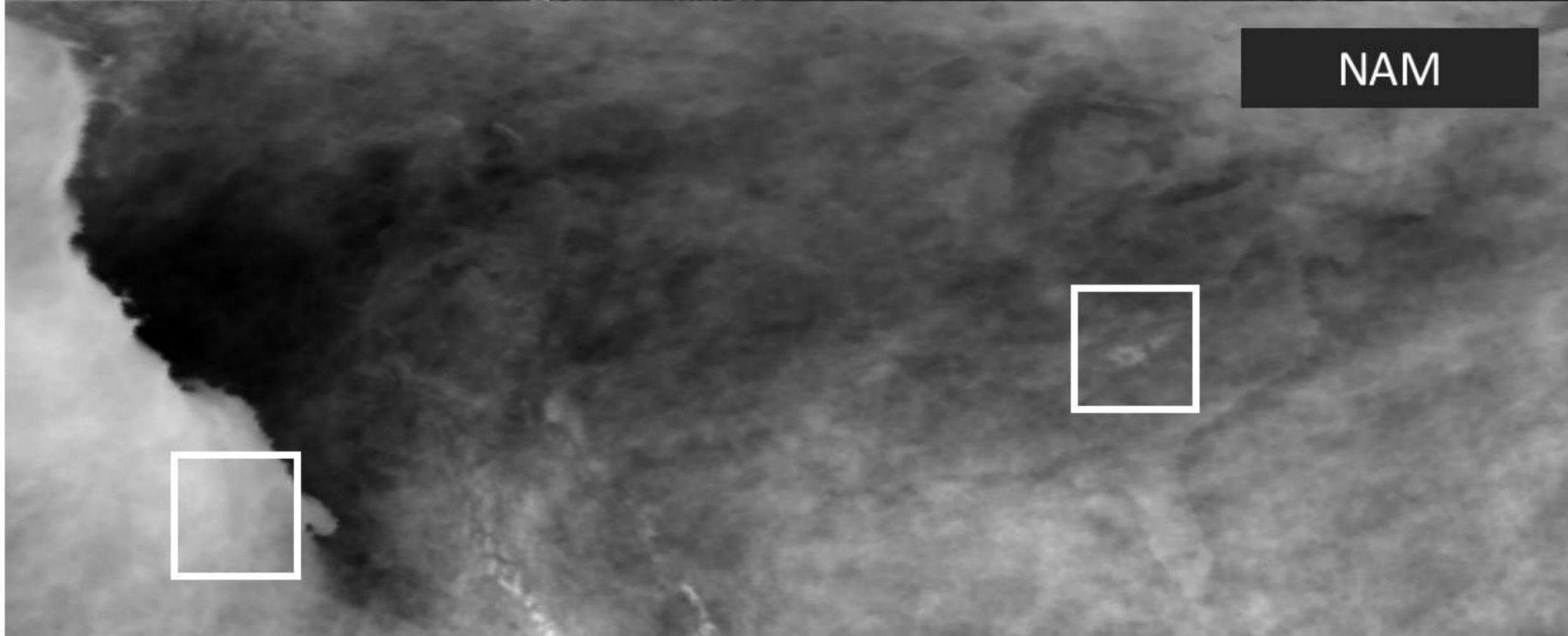
July, August, September 2010 mean; 0Z NAM run; 18 hour forecast



Note: view most results shown in this talk qualitatively
values will change with threshold chosen...

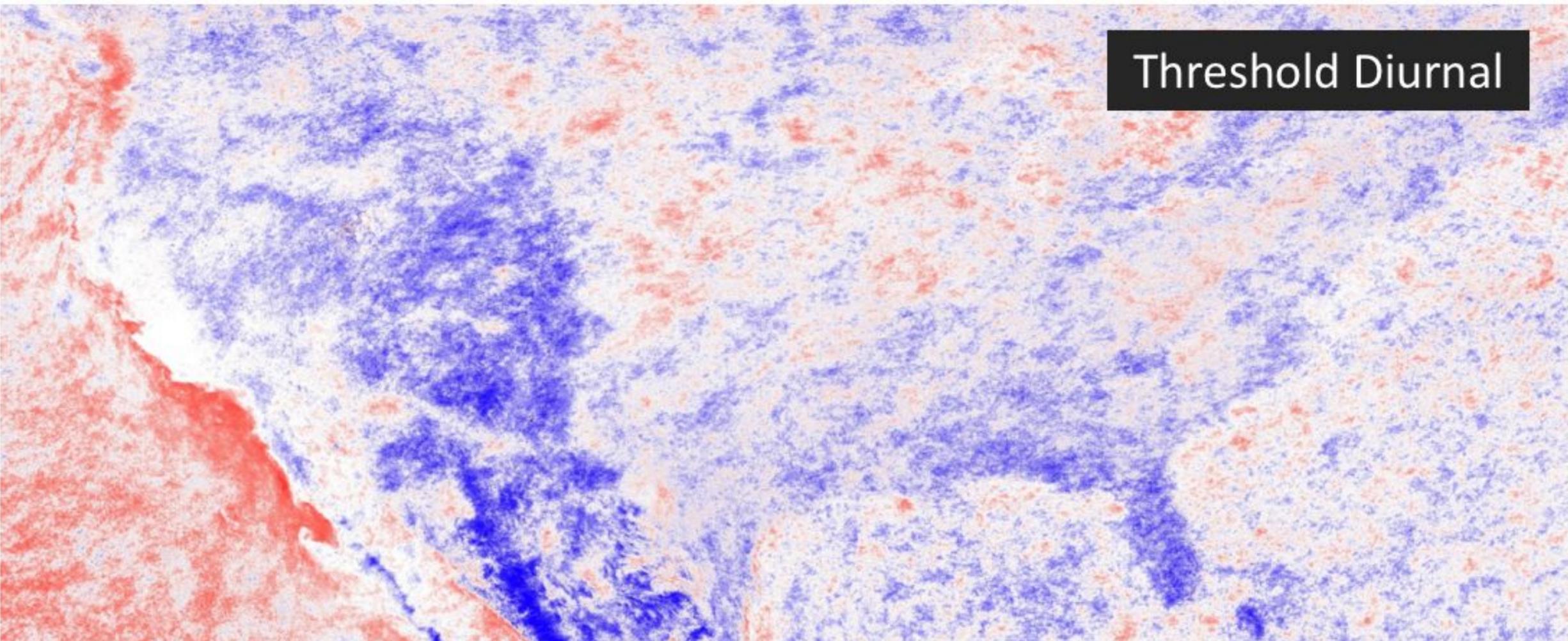


Threshold

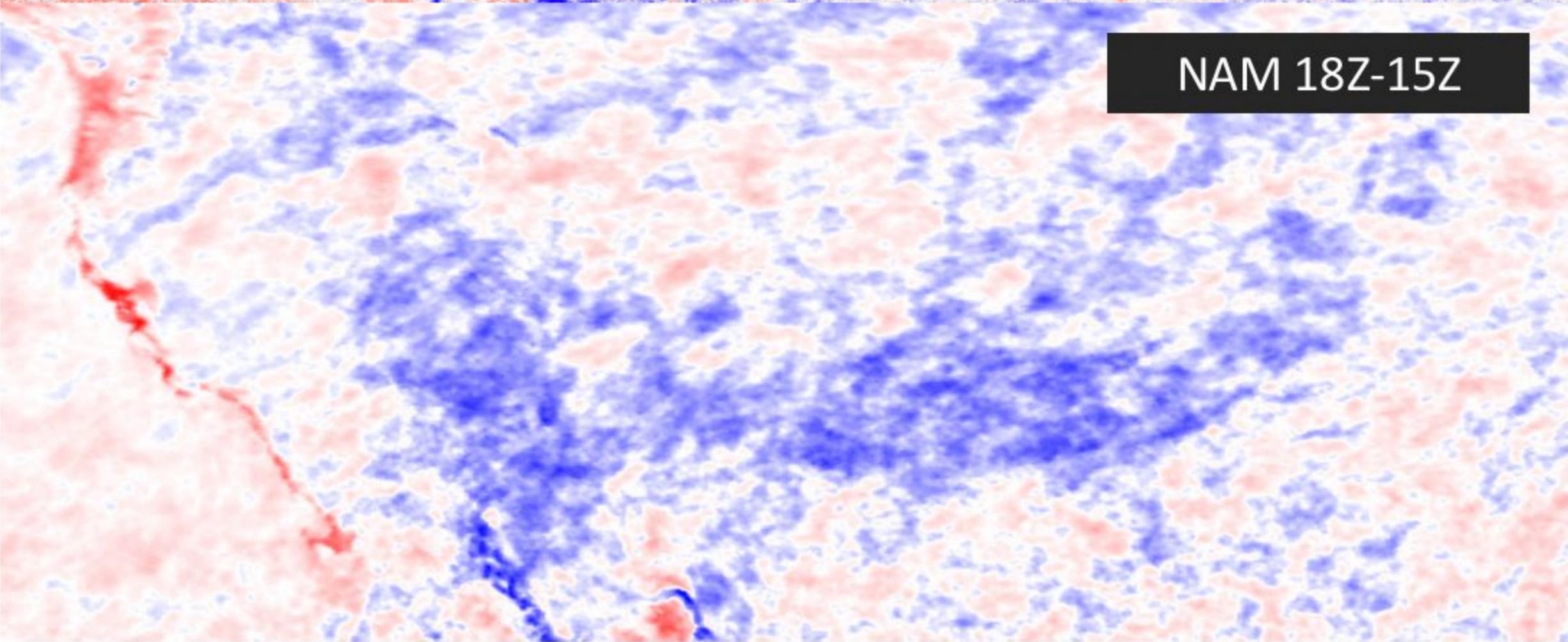


NAM

Threshold and NAM means

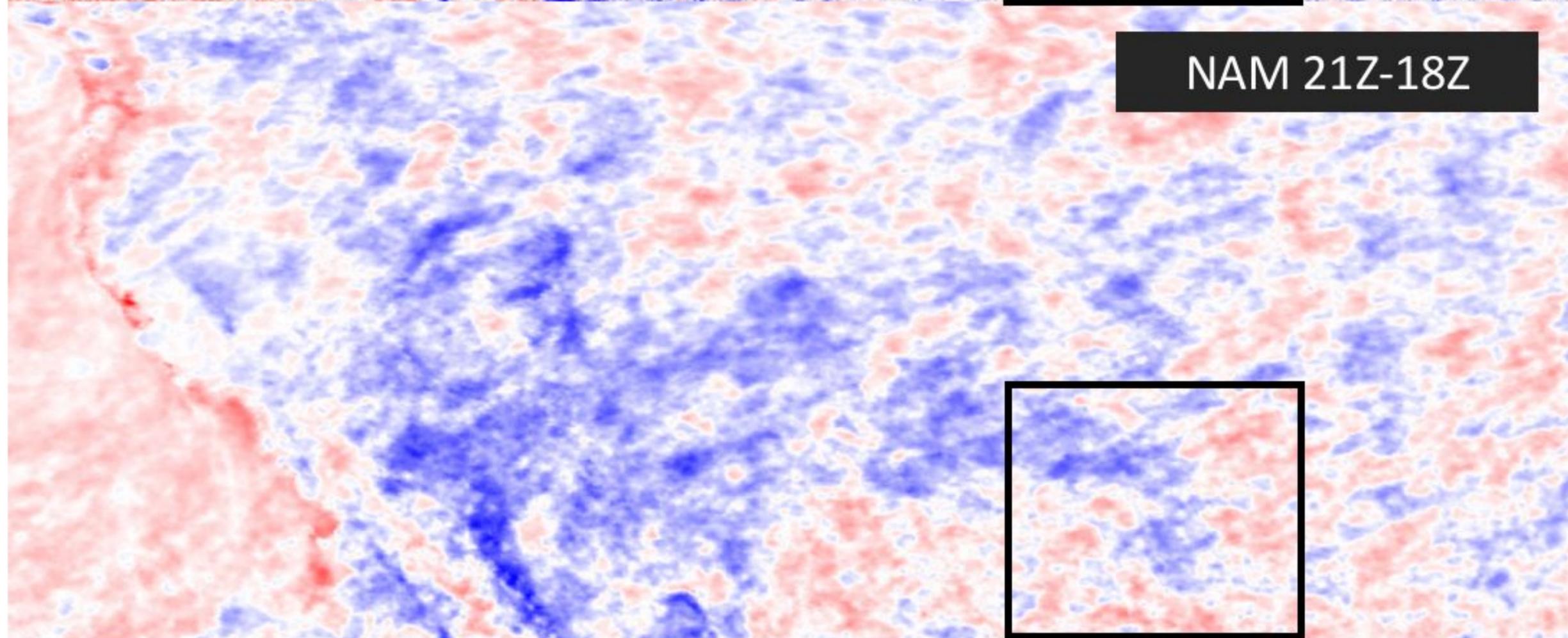
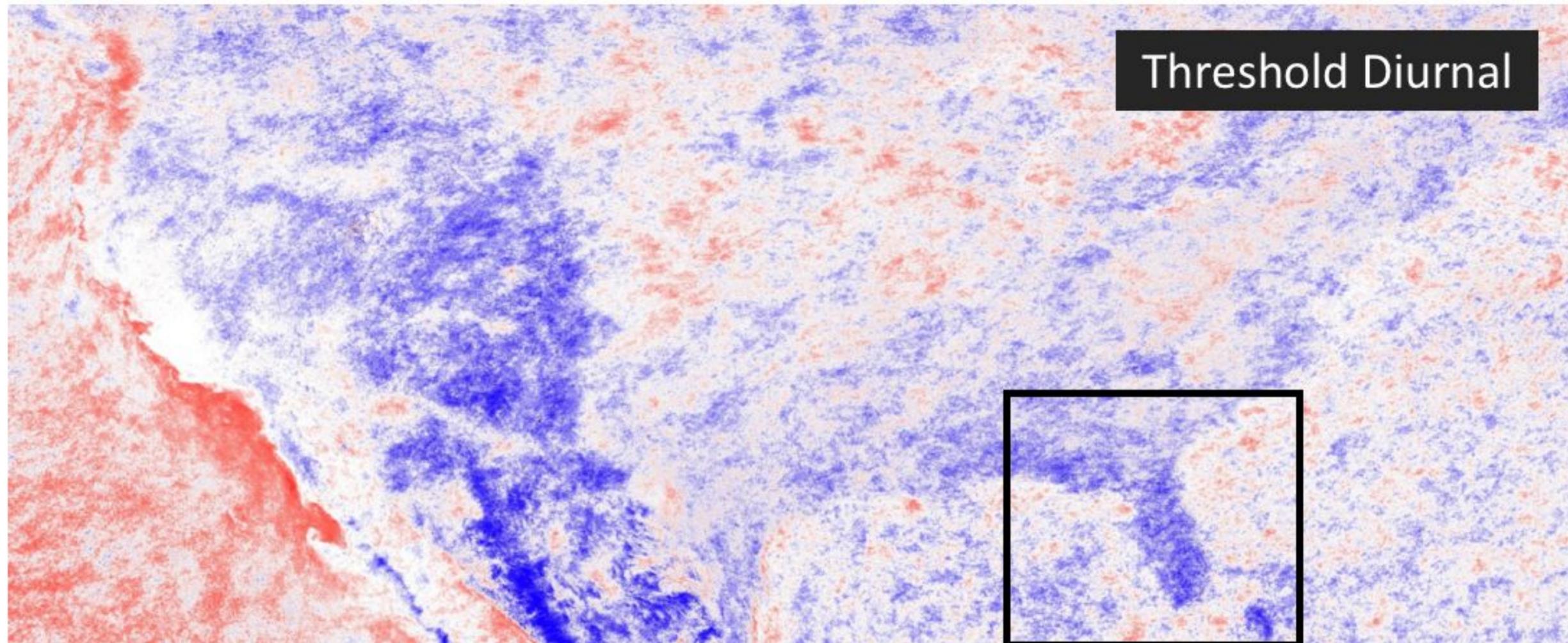


Threshold Diurnal



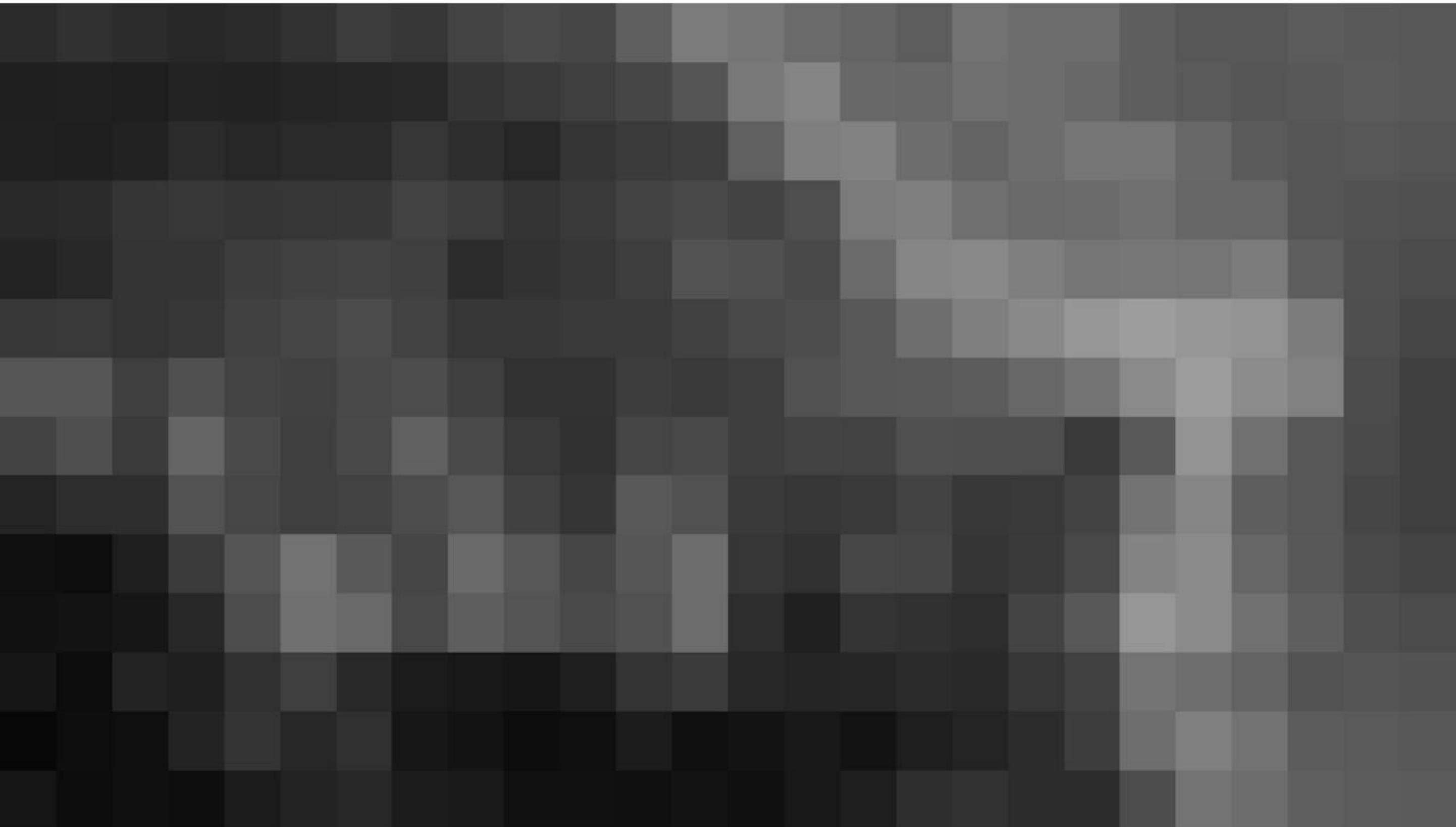
NAM 18Z-15Z

Threshold Aqua minus Terra; NAM 18Z-15Z



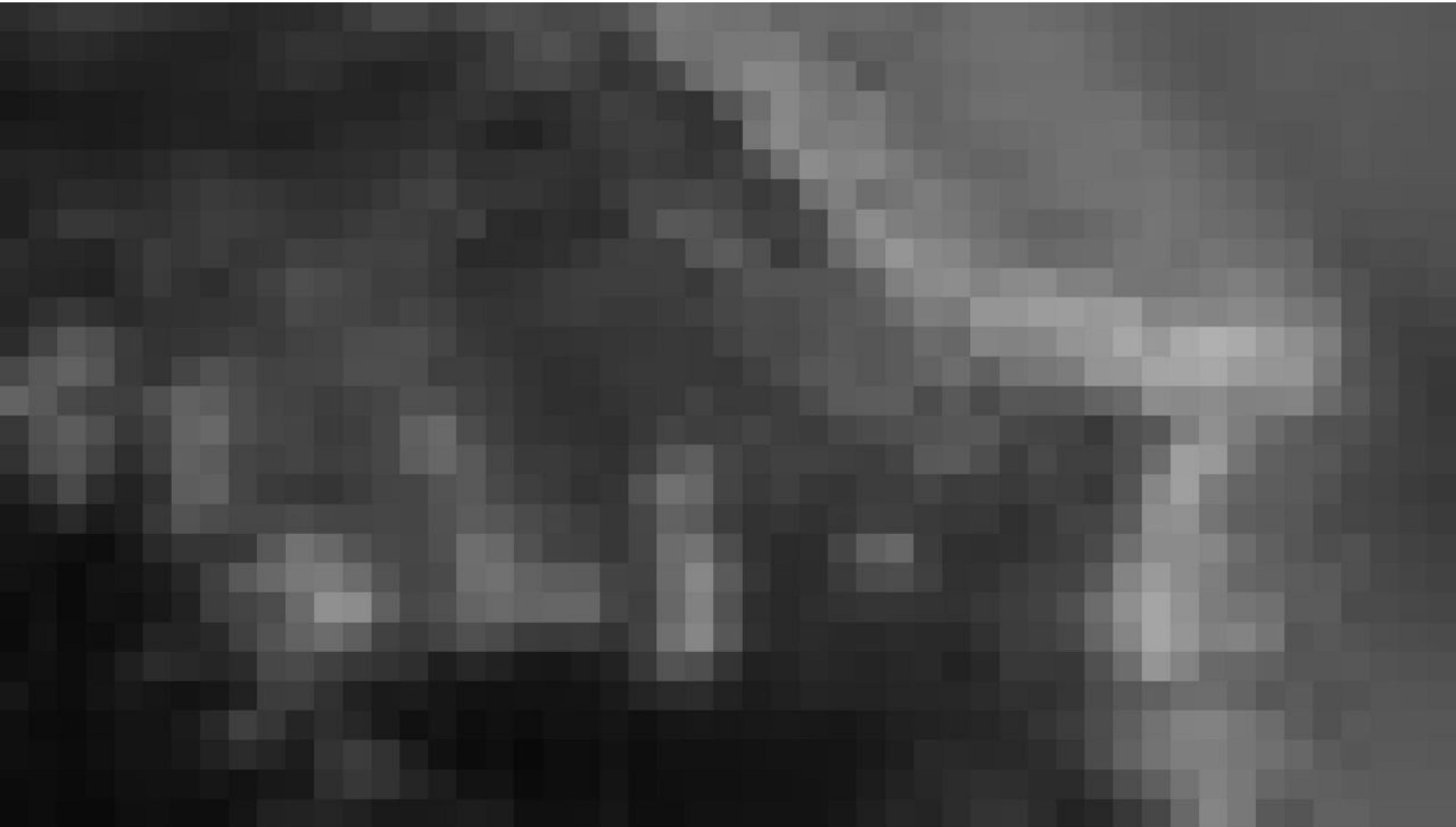
Threshold Aqua minus Terra; NAM 21Z-18Z

Why resolution is important. What processes are controlling the mean cloudiness here?



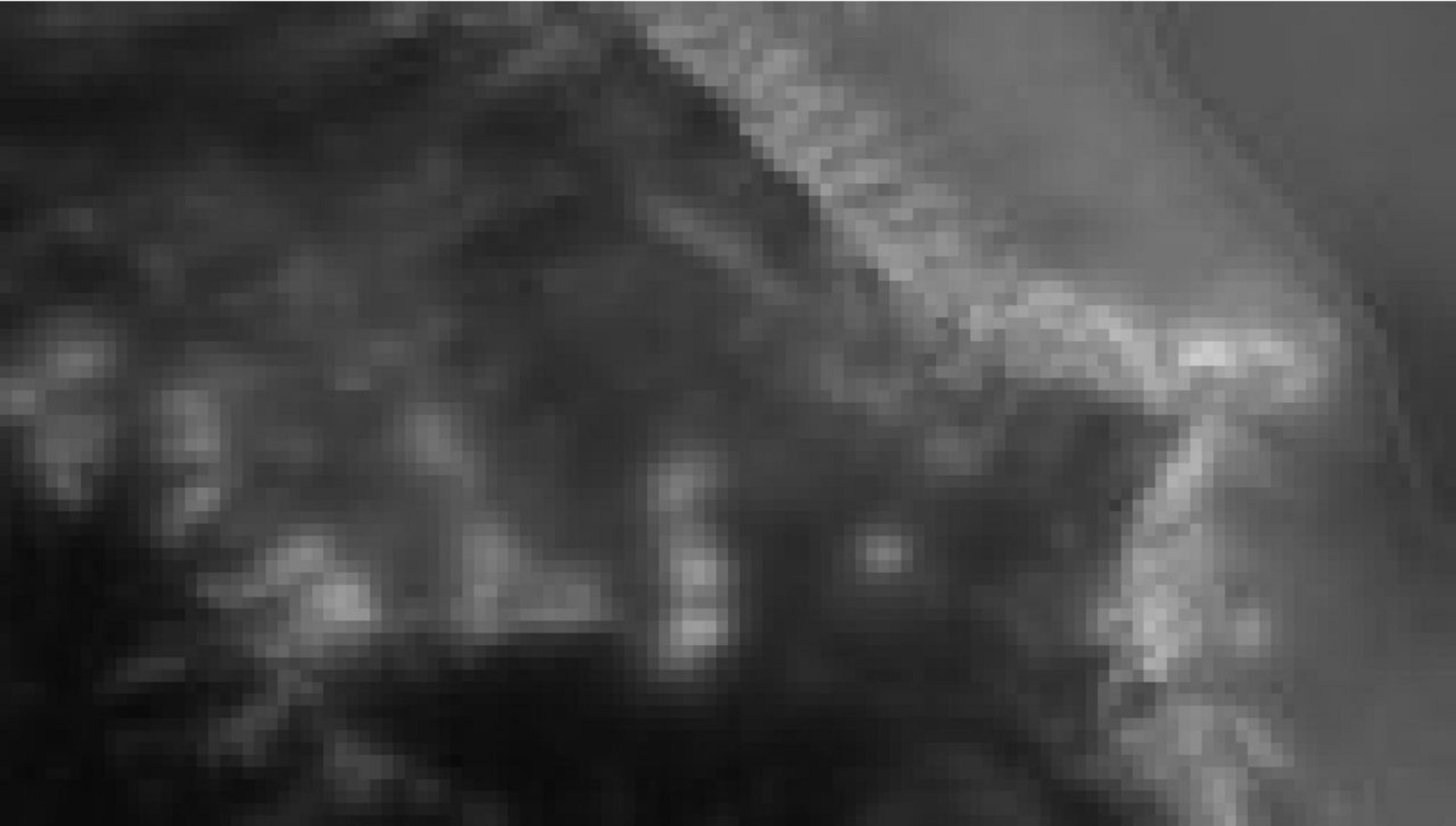
20 km pixels

If we know the geography well we can guess some factors...



10 km pixels

This is central Mexico... Volcanic peaks and steep coastal slopes



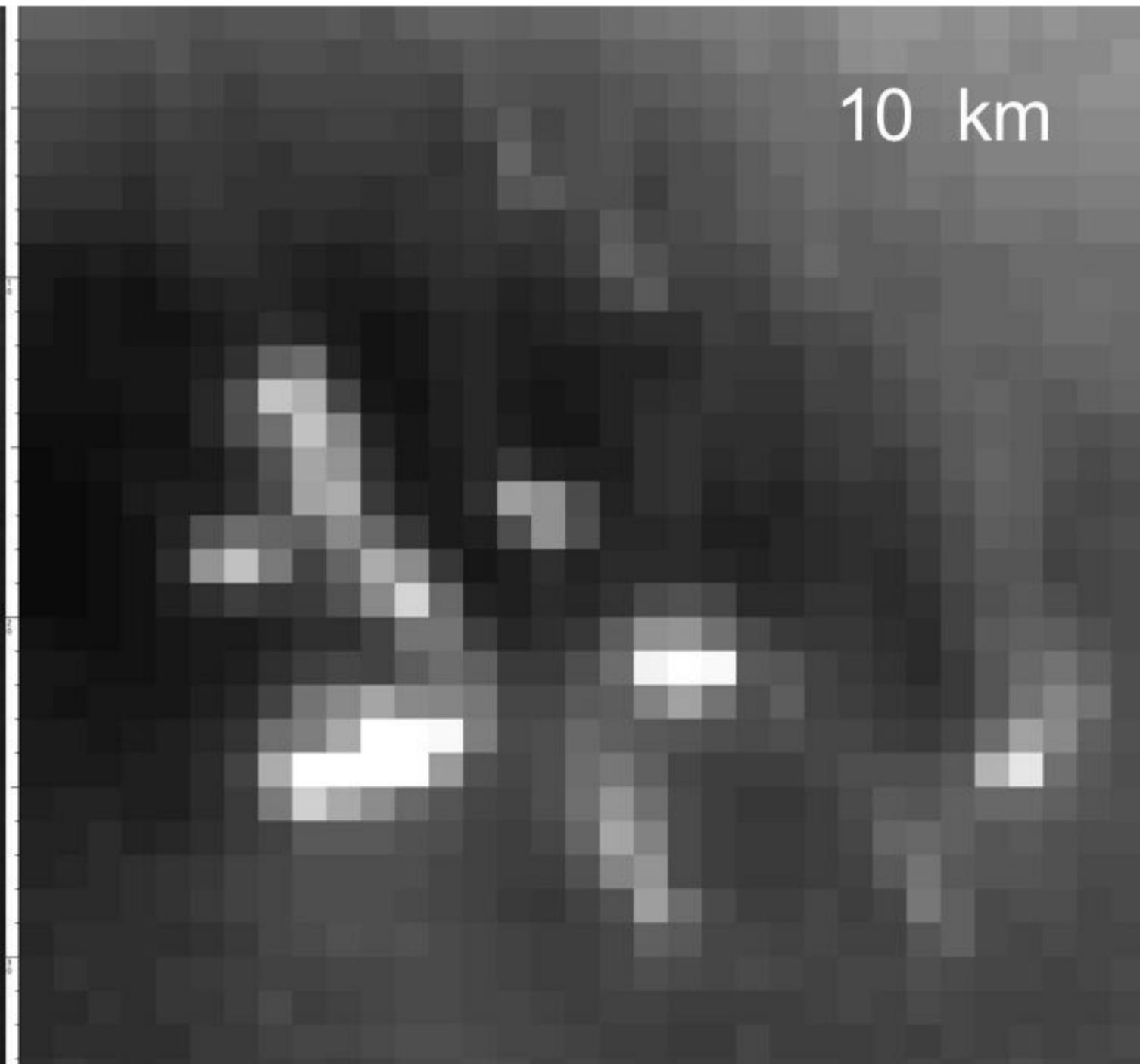
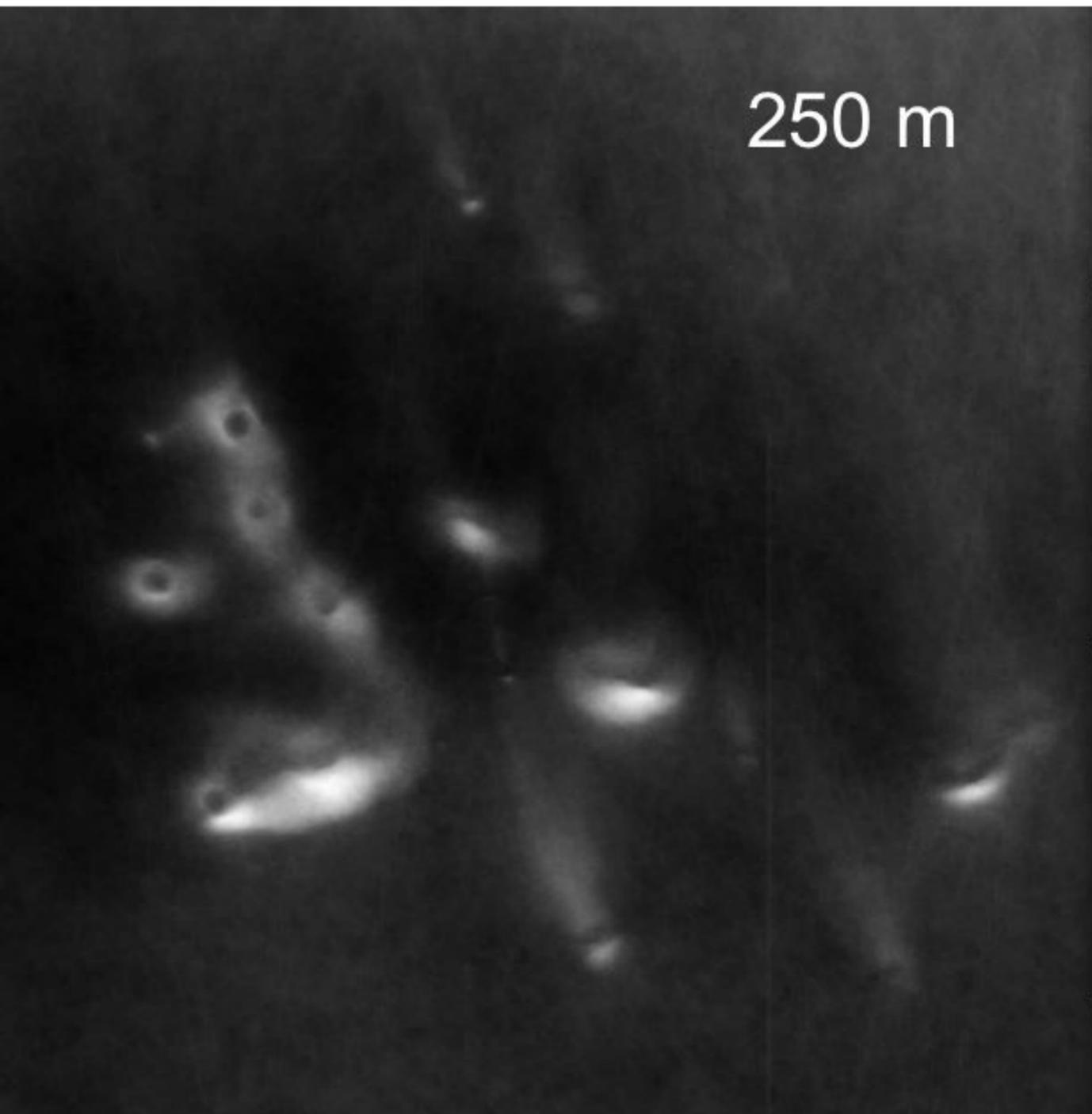
4 km pixels

At full resolution canyon circulations become evident

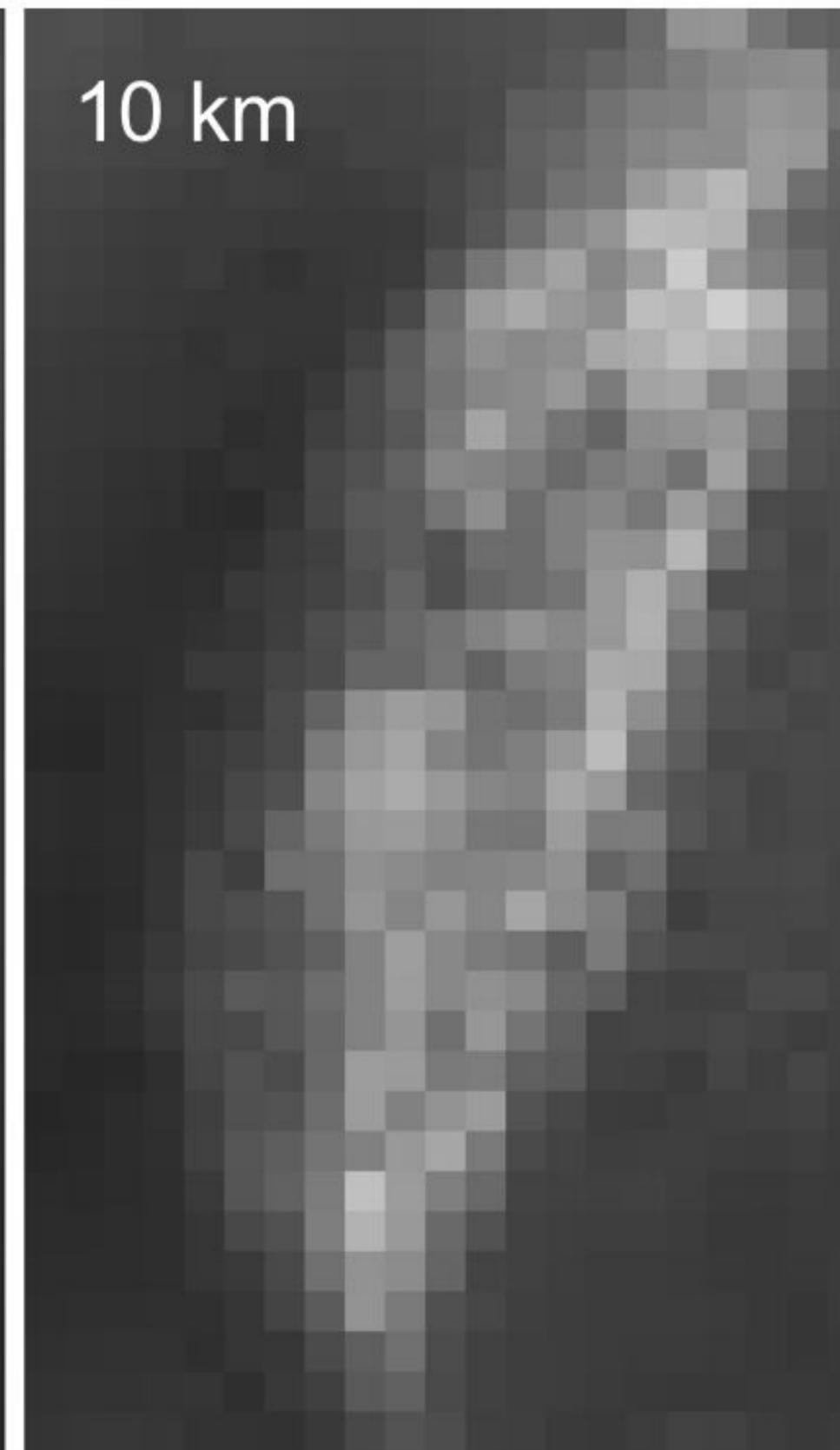
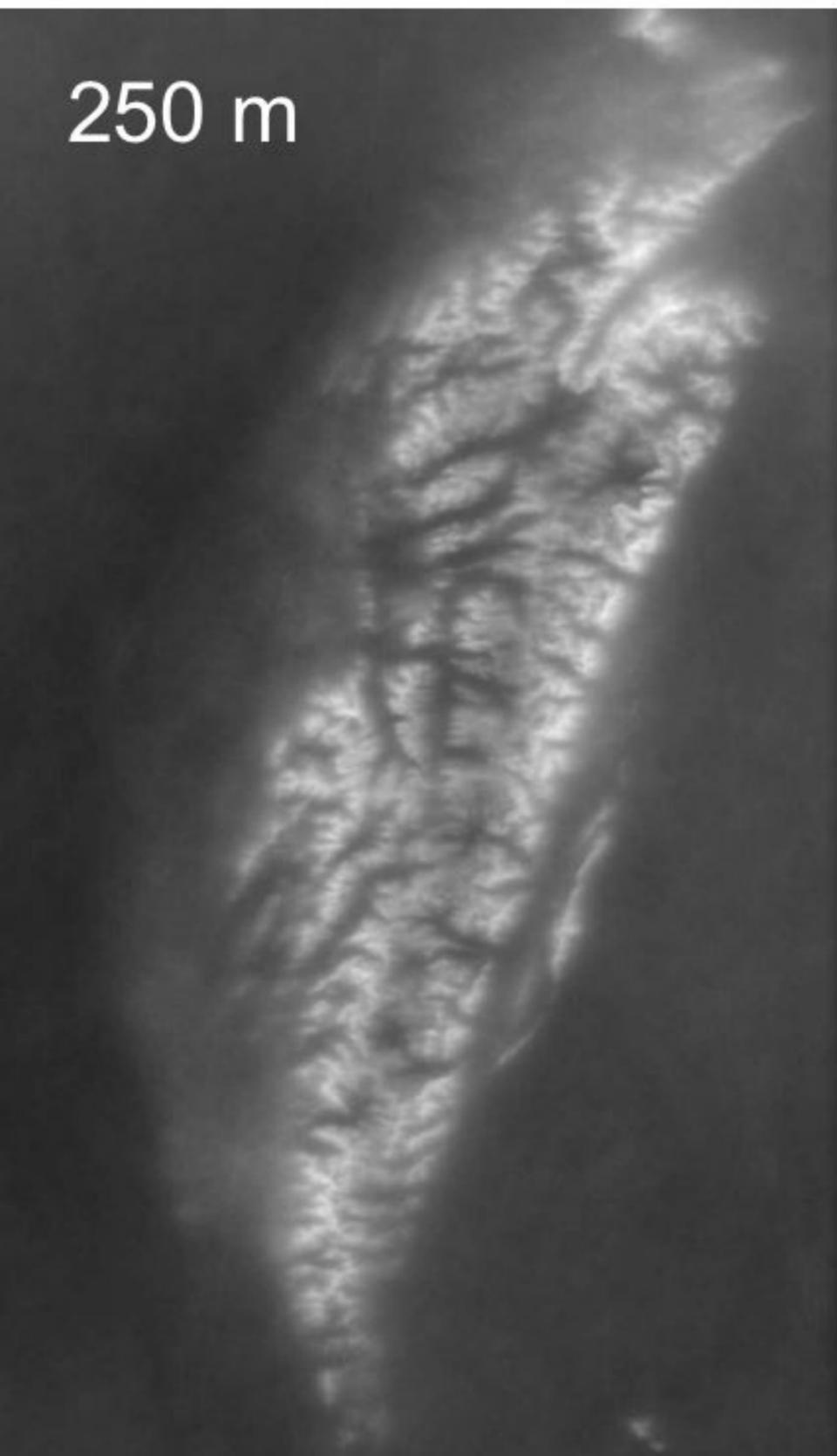


250m pixels

Full resolution is needed to estimate orographic effects
Galapagos Islands - 24 month mean

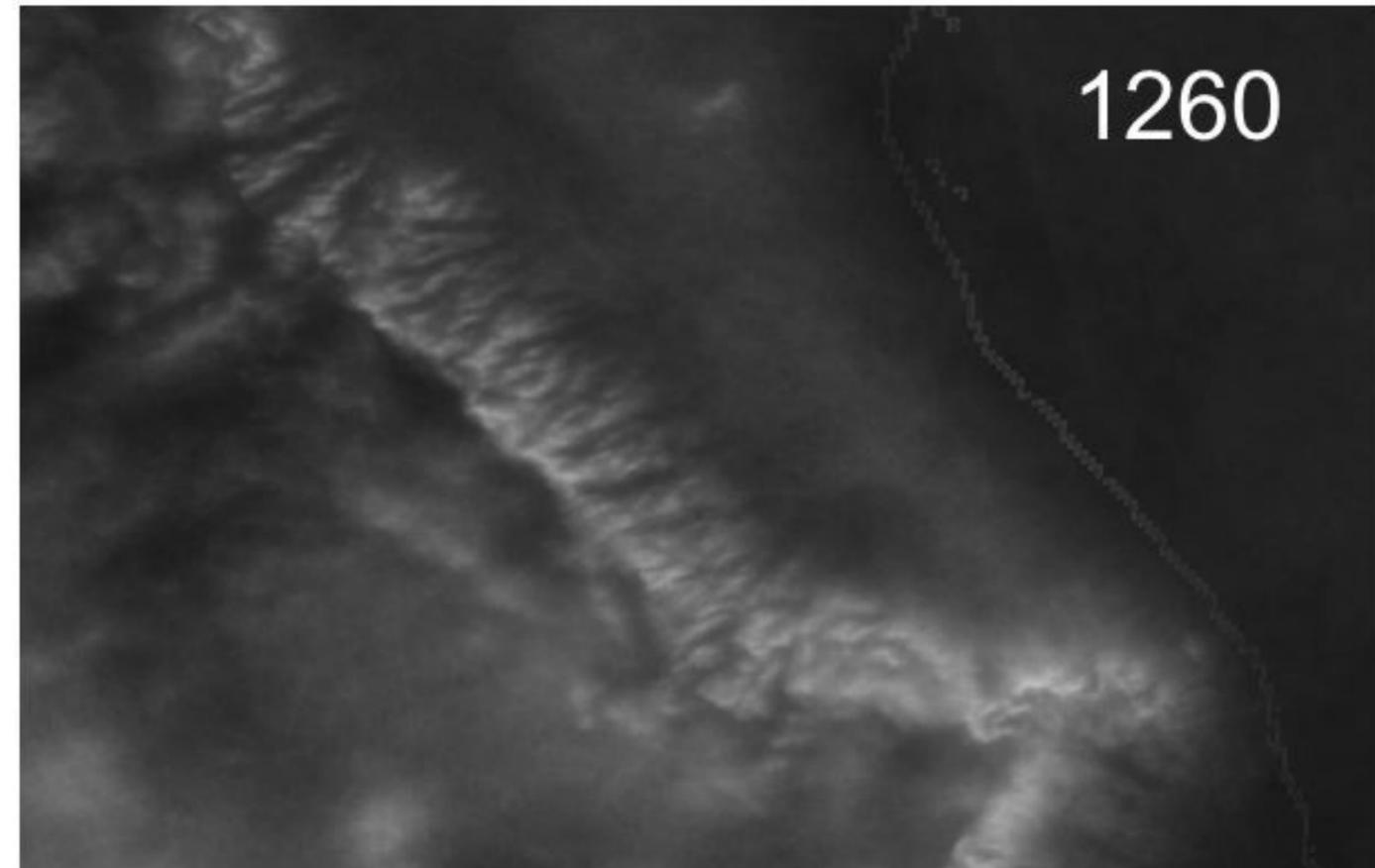
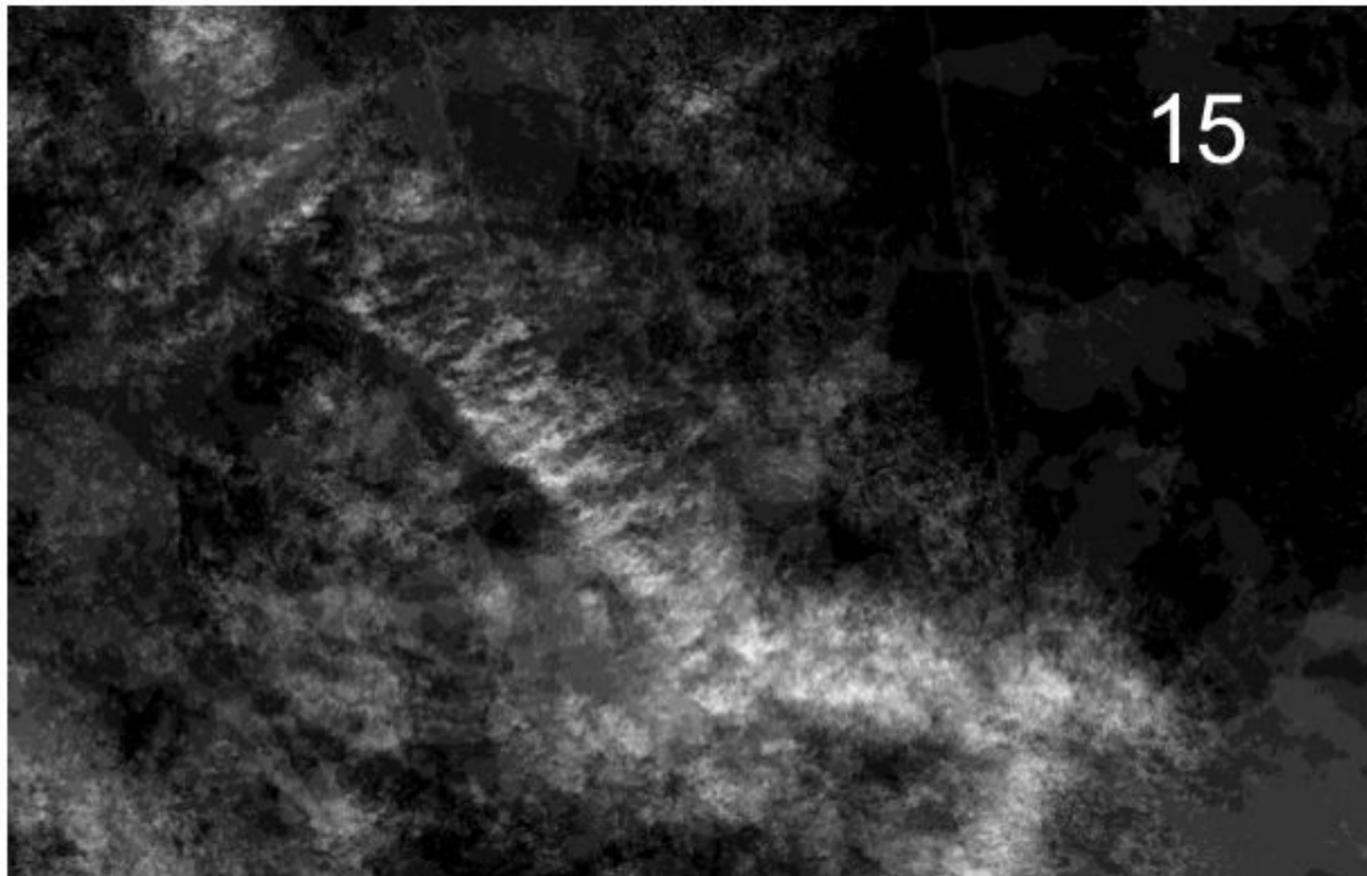
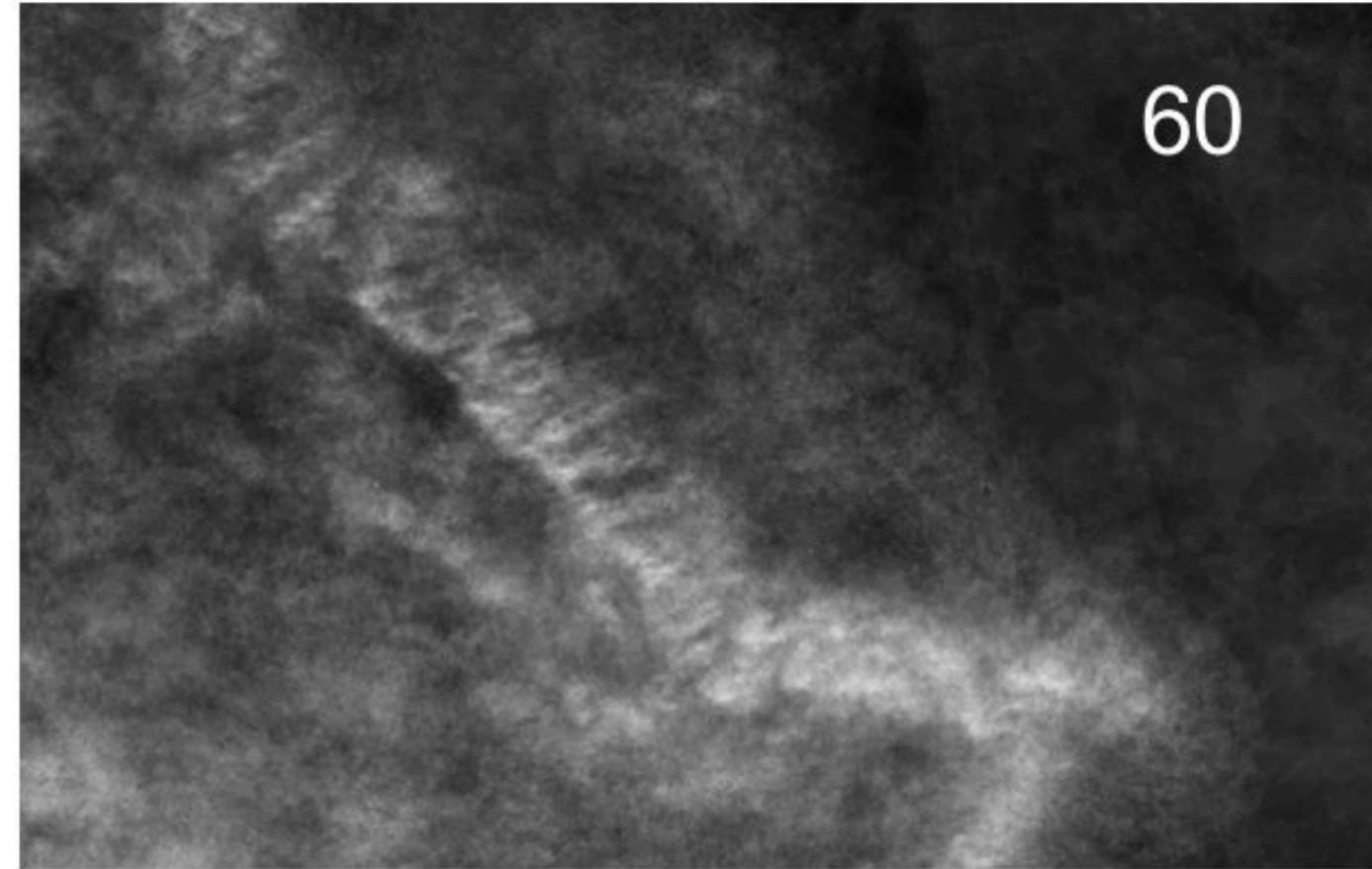
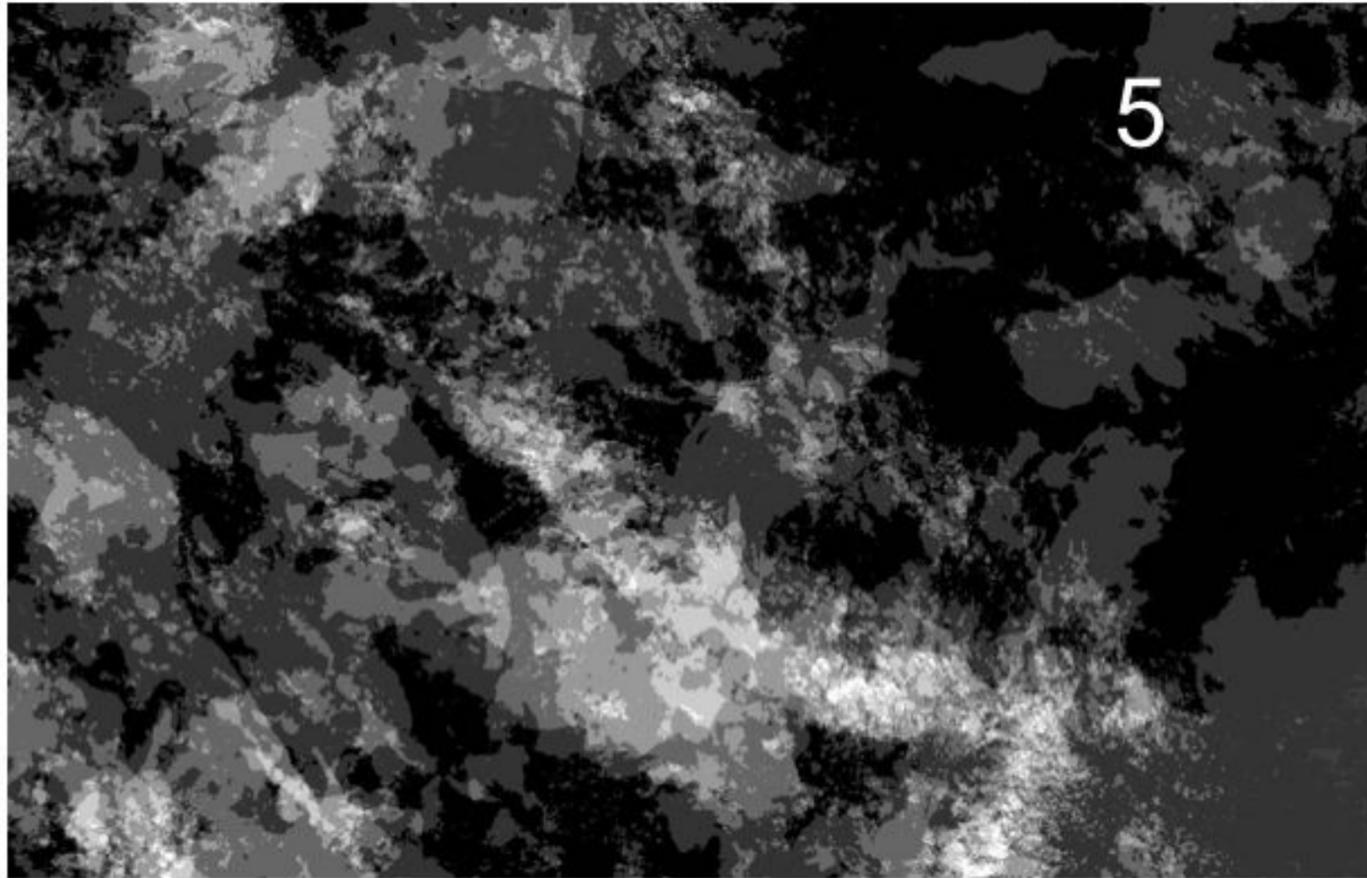


Taiwan annual mean cloudiness
cloud-modulating processes only evident at high resolution



~ 84 month mean

Relatively few days required to capture “climatology”
where topographic forcing is strong



Basic results - USA May-Oct cloudiness (aqua+terra)

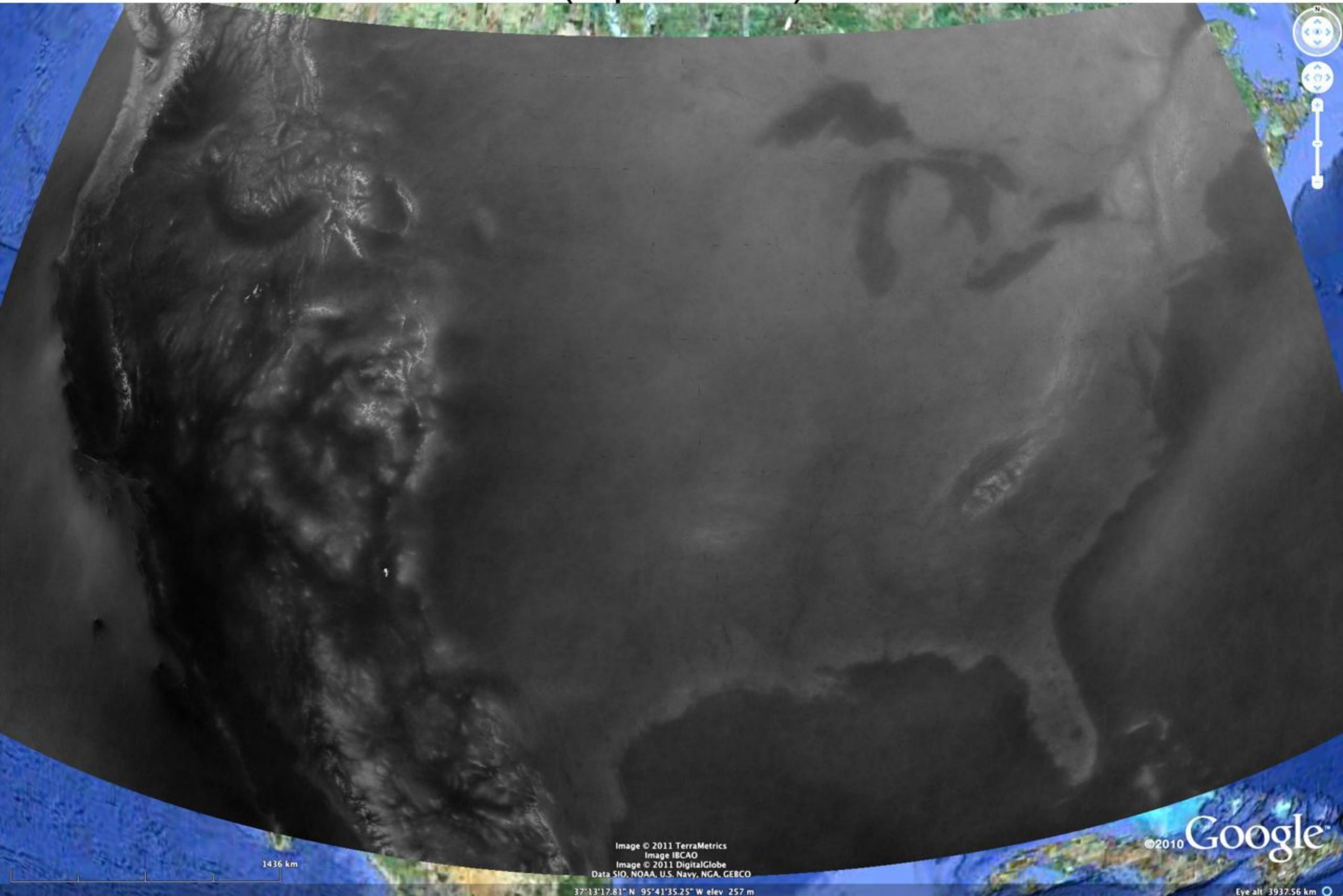


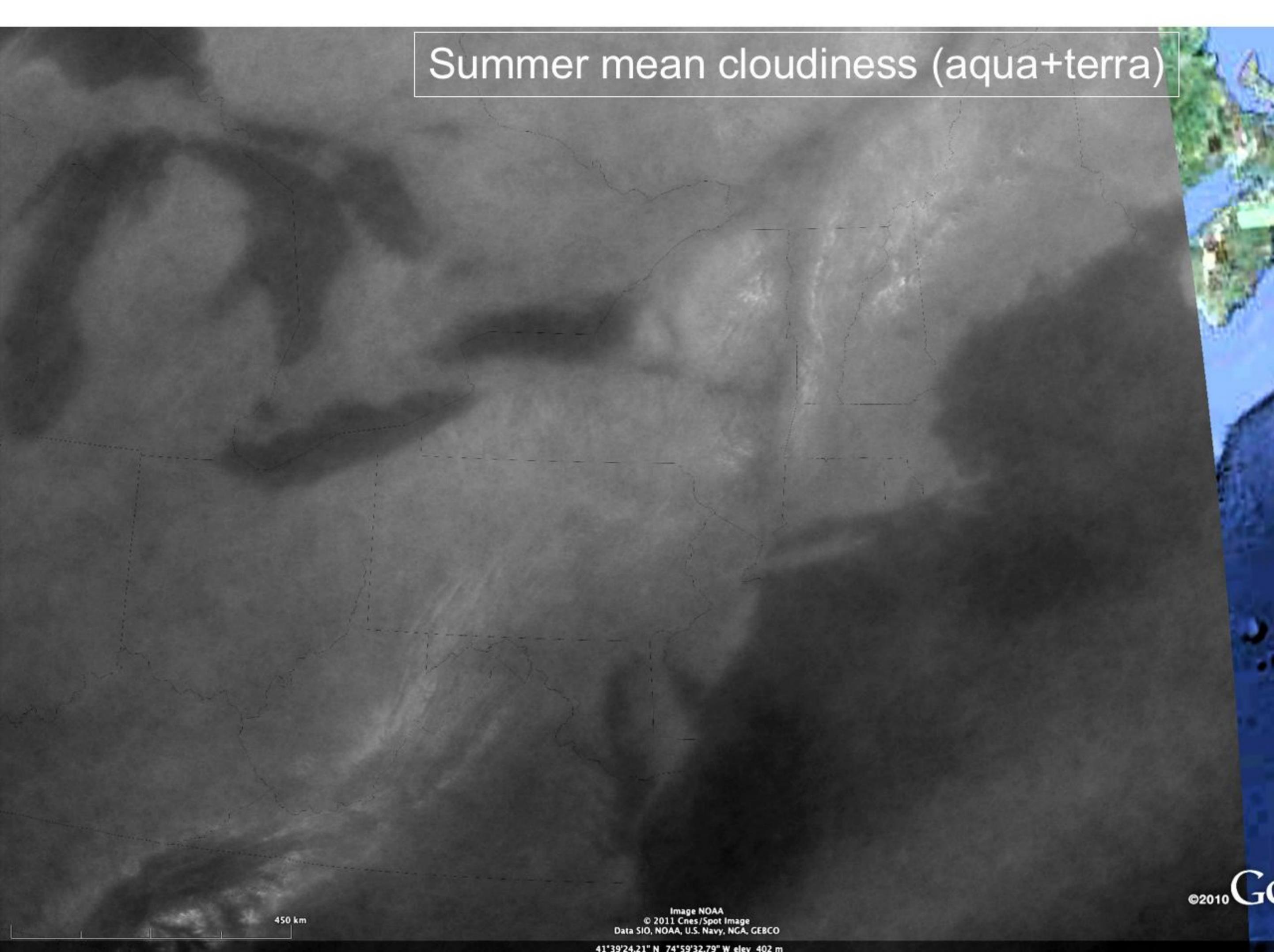
Image © 2011 TerraMetrics
Image IBCAO
Image © 2011 DigitalGlobe
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

37°13'17.81" N 95°41'35.25" W elev 257 m

©2010 Google™

Eye alt 3937.56 km

Summer mean cloudiness (aqua+terra)



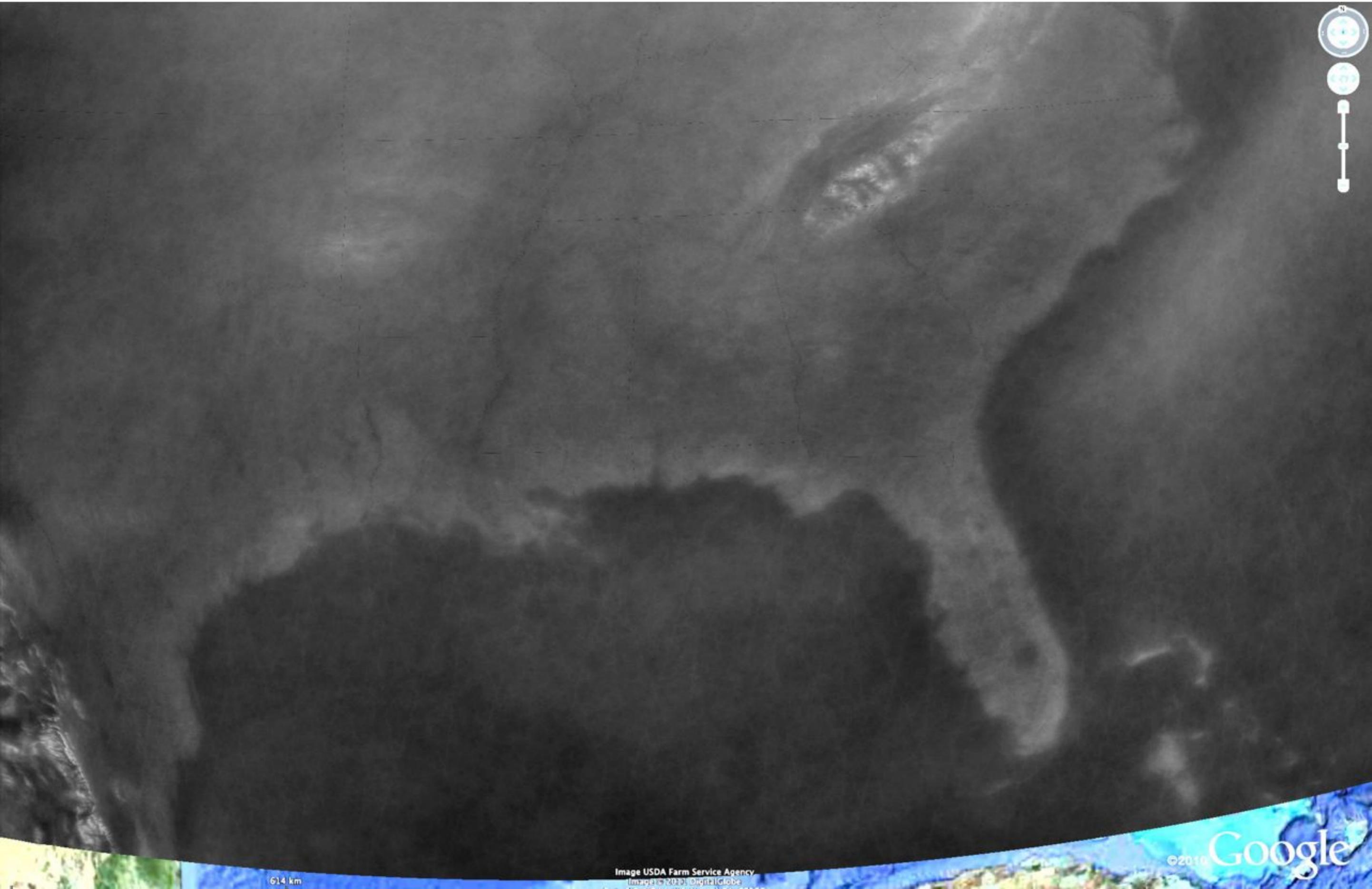
450 km

Image NOAA
© 2011 Cnes/Spot Image
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

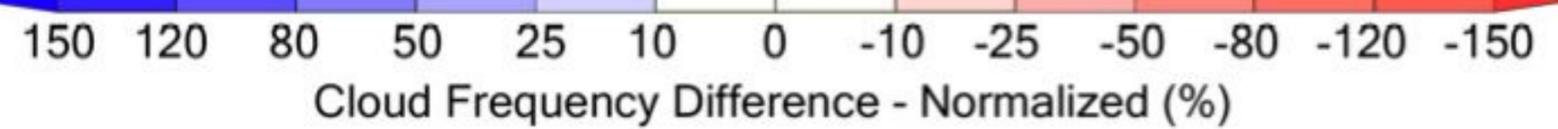
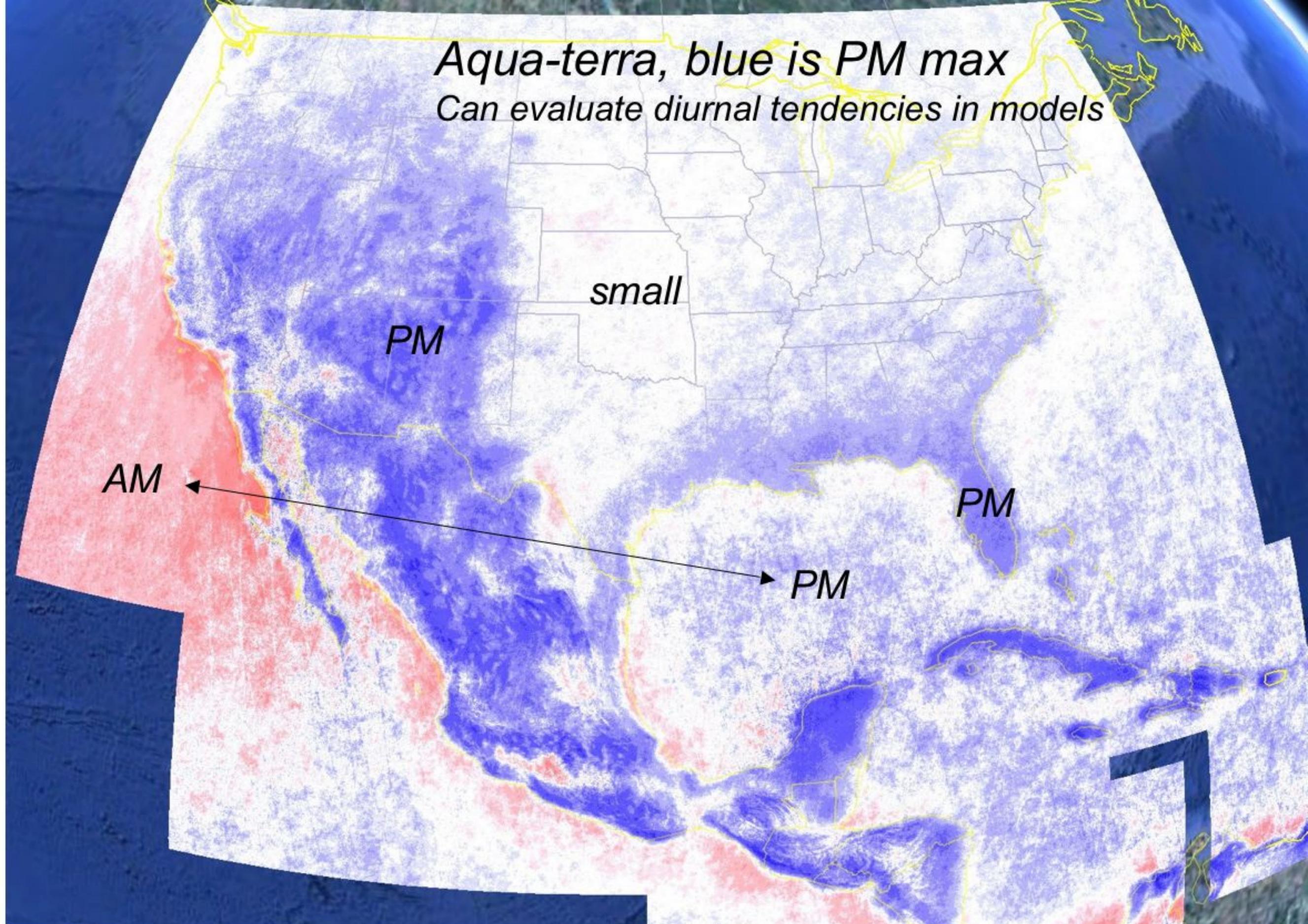
41°39'24.21" N 74°59'32.79" W elev 402 m

Summer mean cloudiness (aqua+terra)

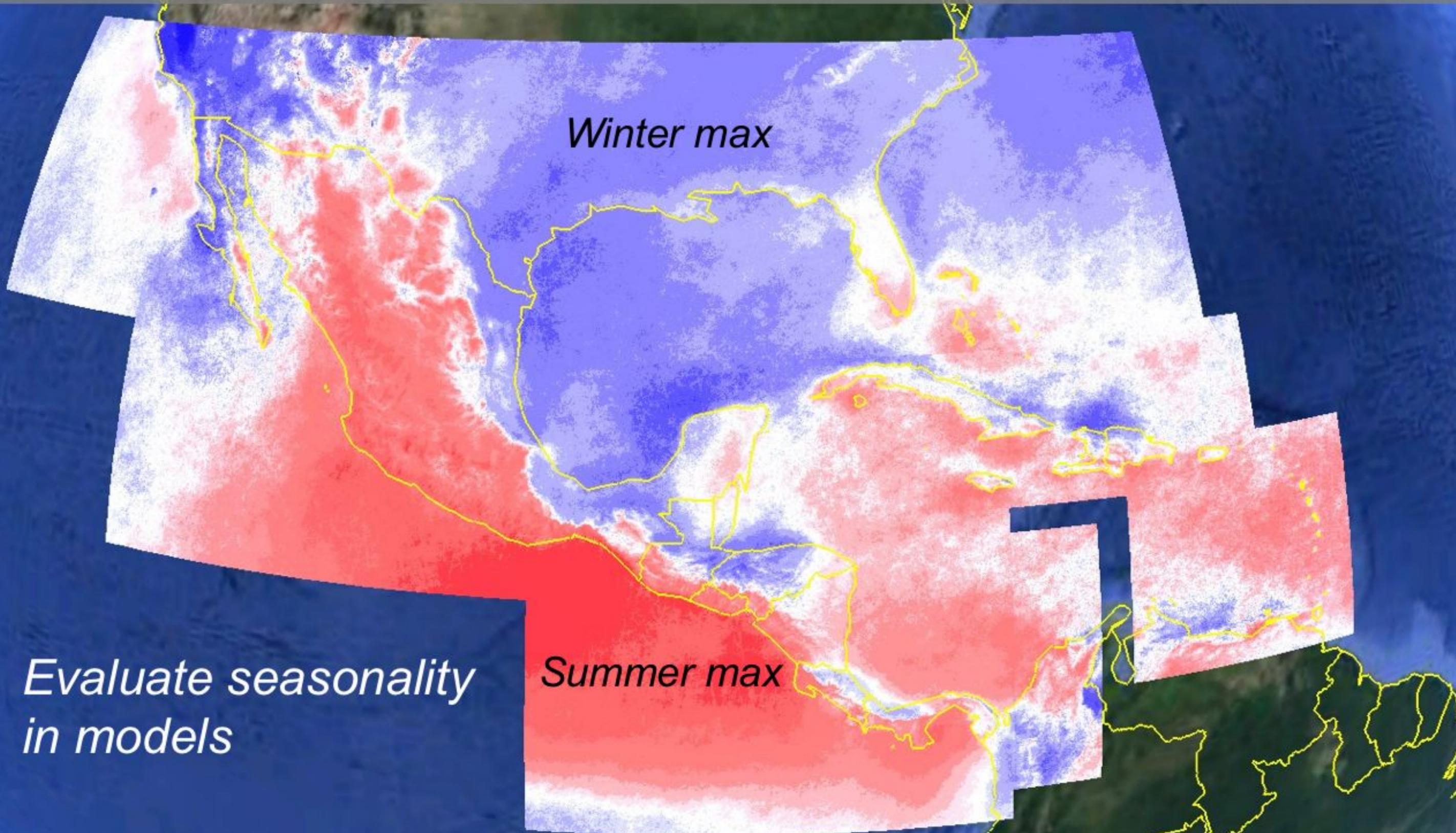
Sea breeze evidence, lakes, hills etc



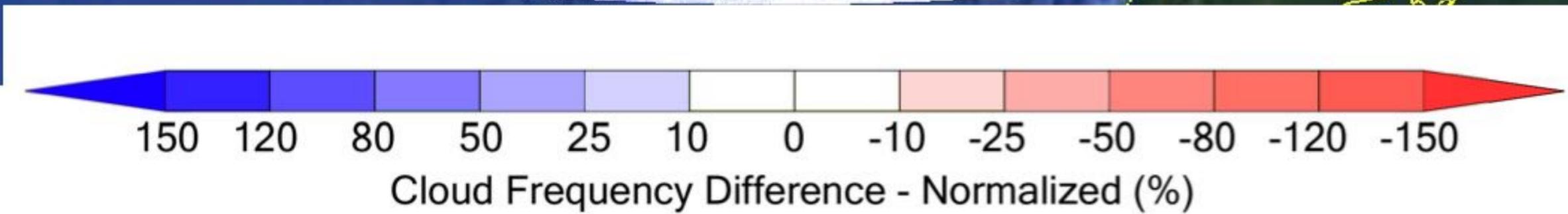
Aqua-terra, blue is PM max
Can evaluate diurnal tendencies in models



Winter minus summer, red is summer max

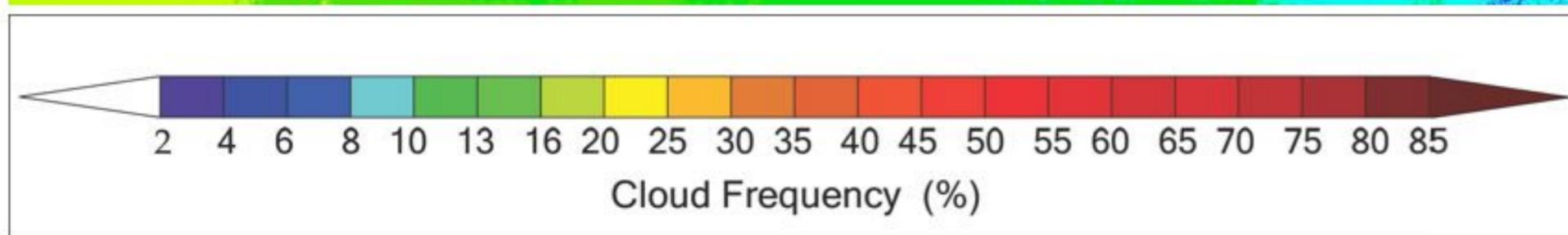
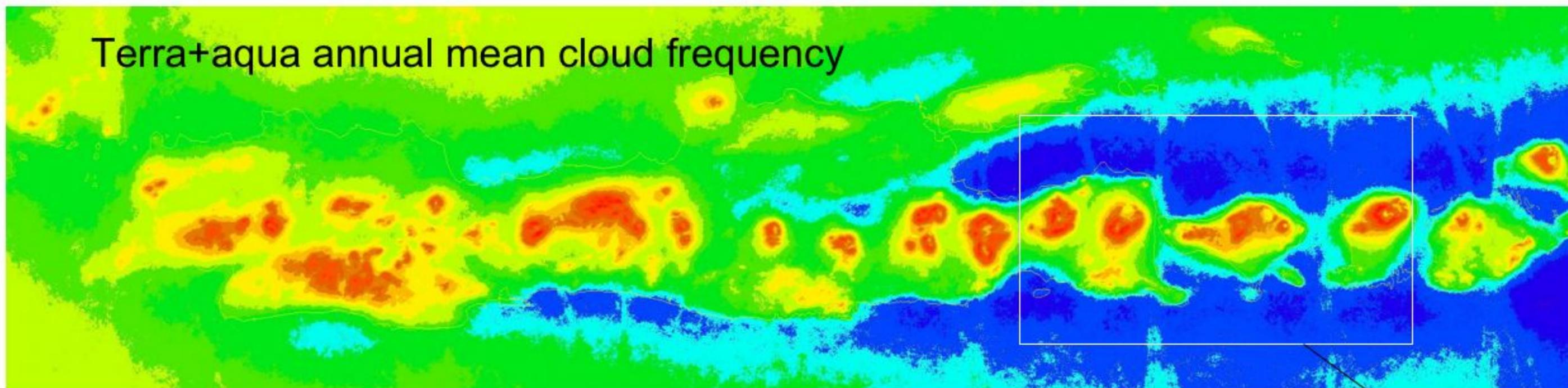
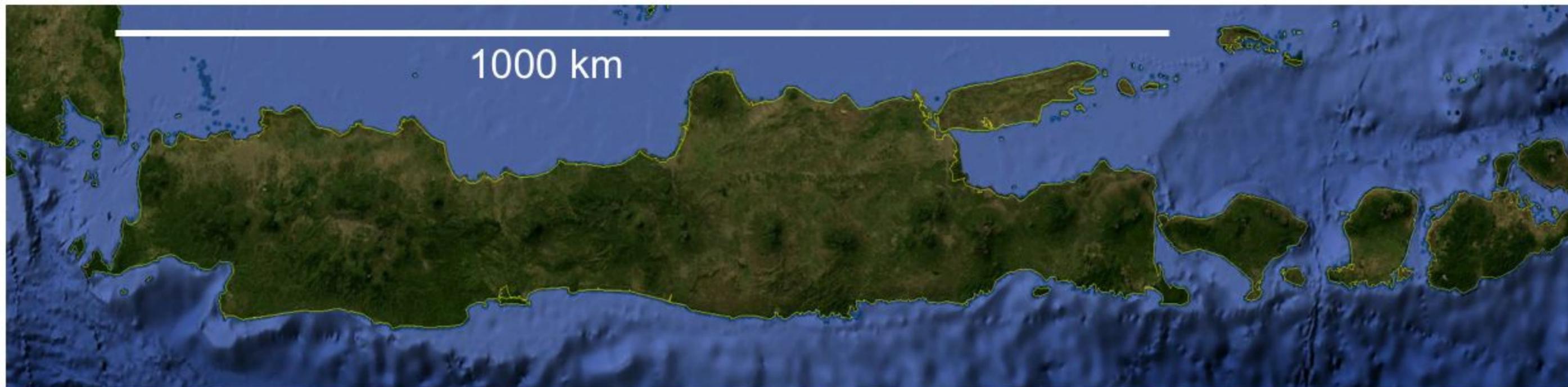


*Evaluate seasonality
in models*



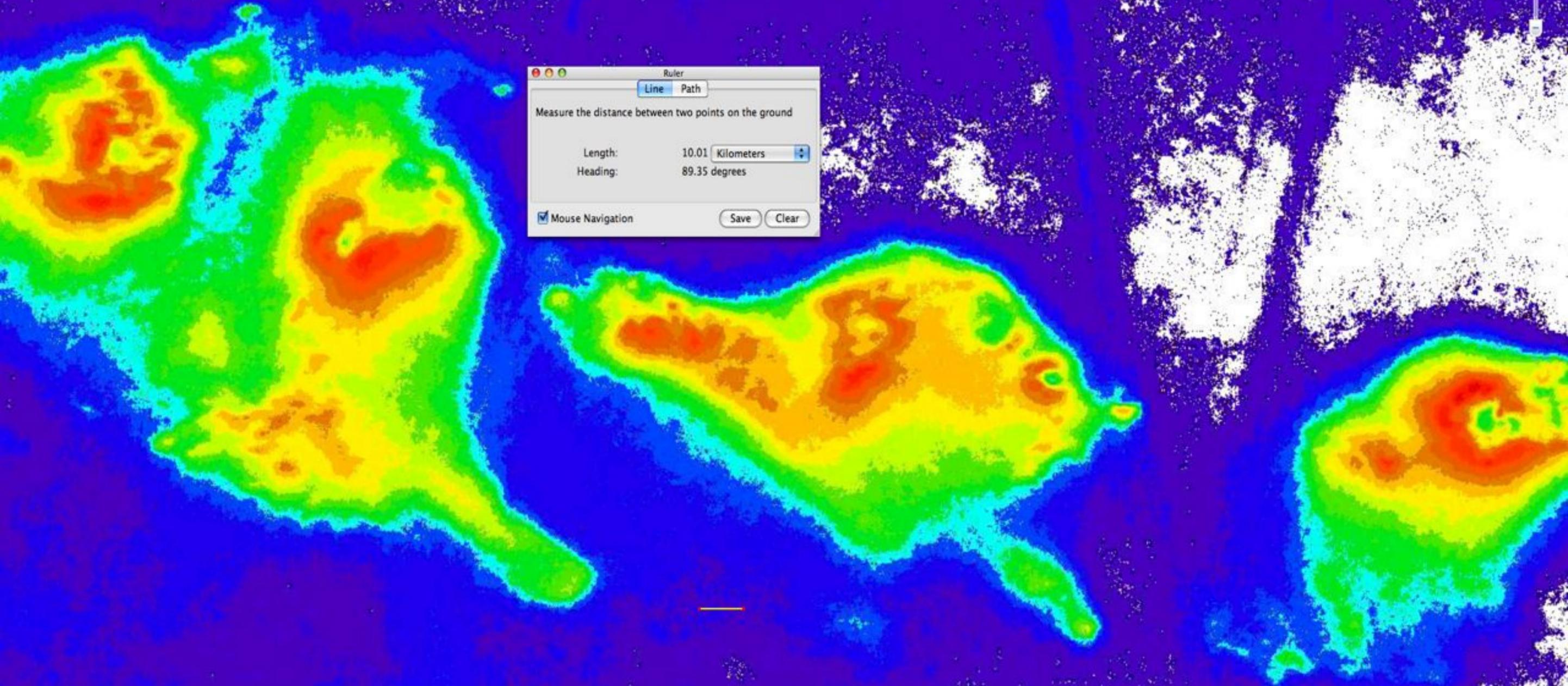
Some examples of why these products might
be of value to
NWS and other Met Service forecasters

Island of Java, Indonesia, population ~140 million
size ~ a smaller California



Next slide

May-Oct mean aqua+terra



Ruler

Line Path

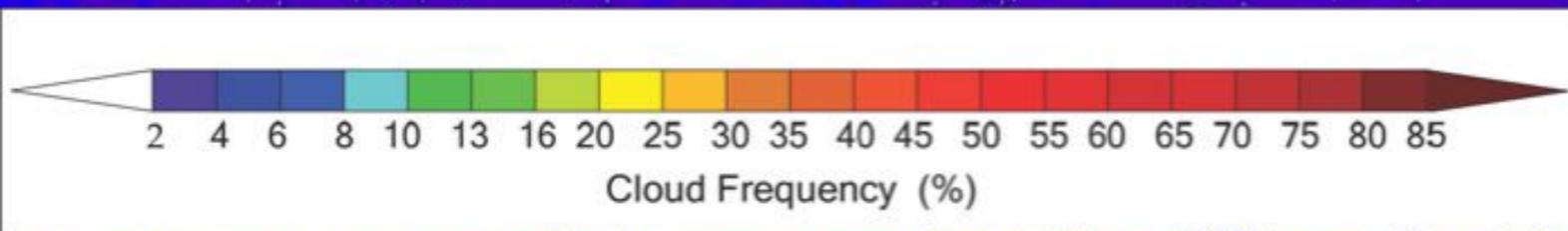
Measure the distance between two points on the ground

Length: 10.01 Kilometers

Heading: 89.35 degrees

Mouse Navigation

Save Clear

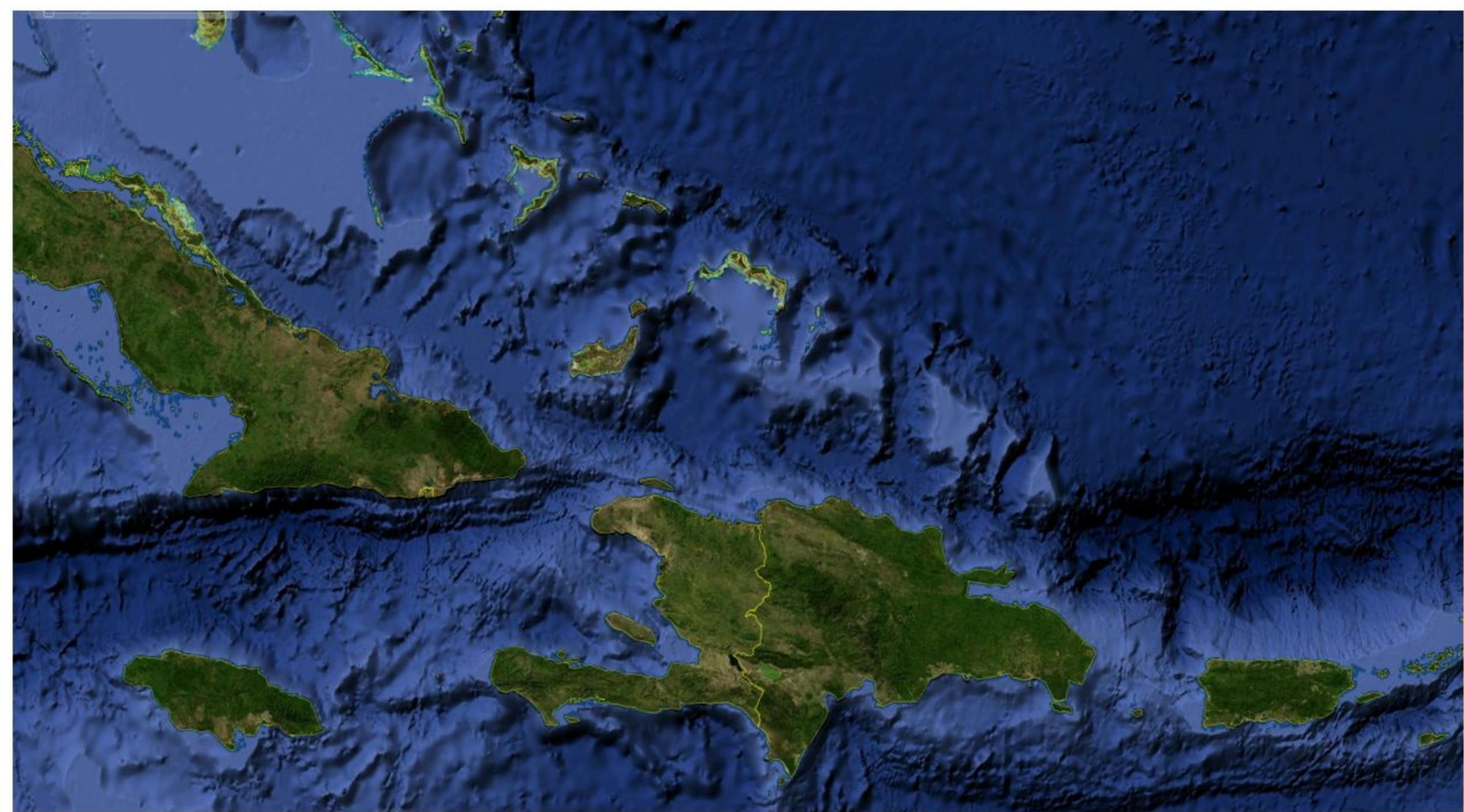


72 km

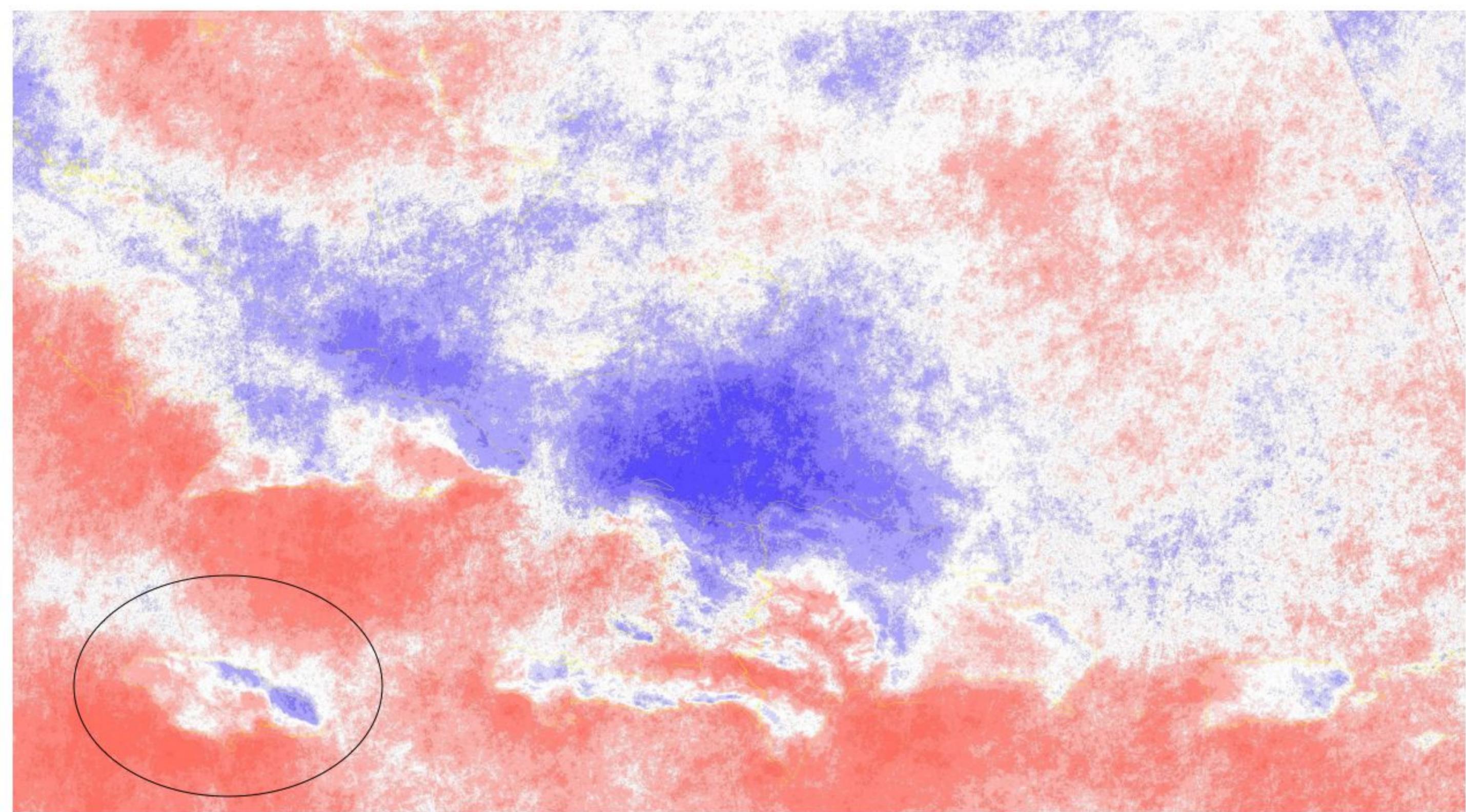
Data SIO, NOAA, U.S. Navy, NGA, GEBCO

Google

Complex geography of Greater Antilles

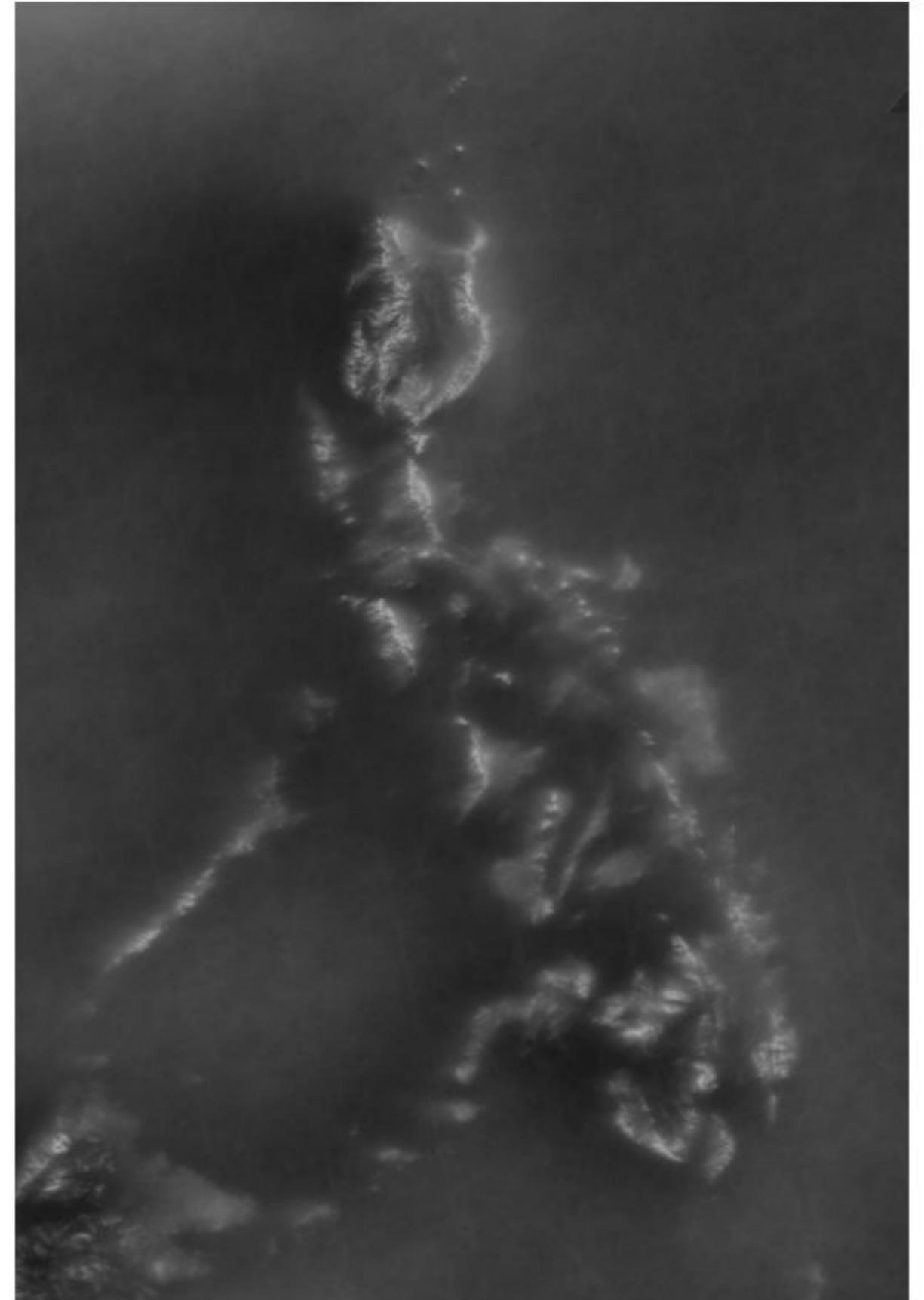


Seasonality of cloudiness flips across most topographic barriers (blue is winter max in cloudiness)



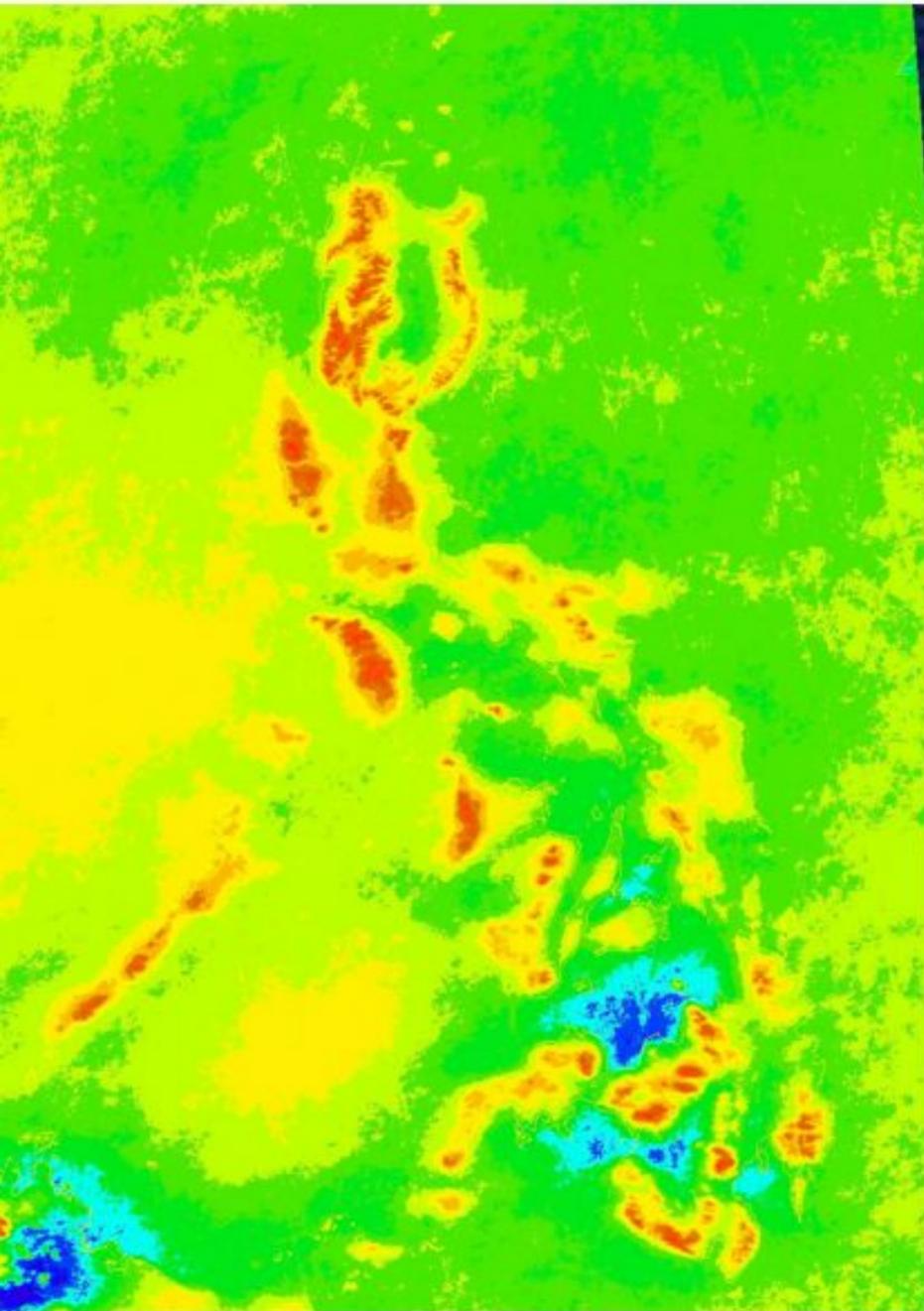
Jamaica (extreme wx events...what was most deadly in Caribbean region?
...understanding seasonality important..)

Consider the complicated geography of the Philippines

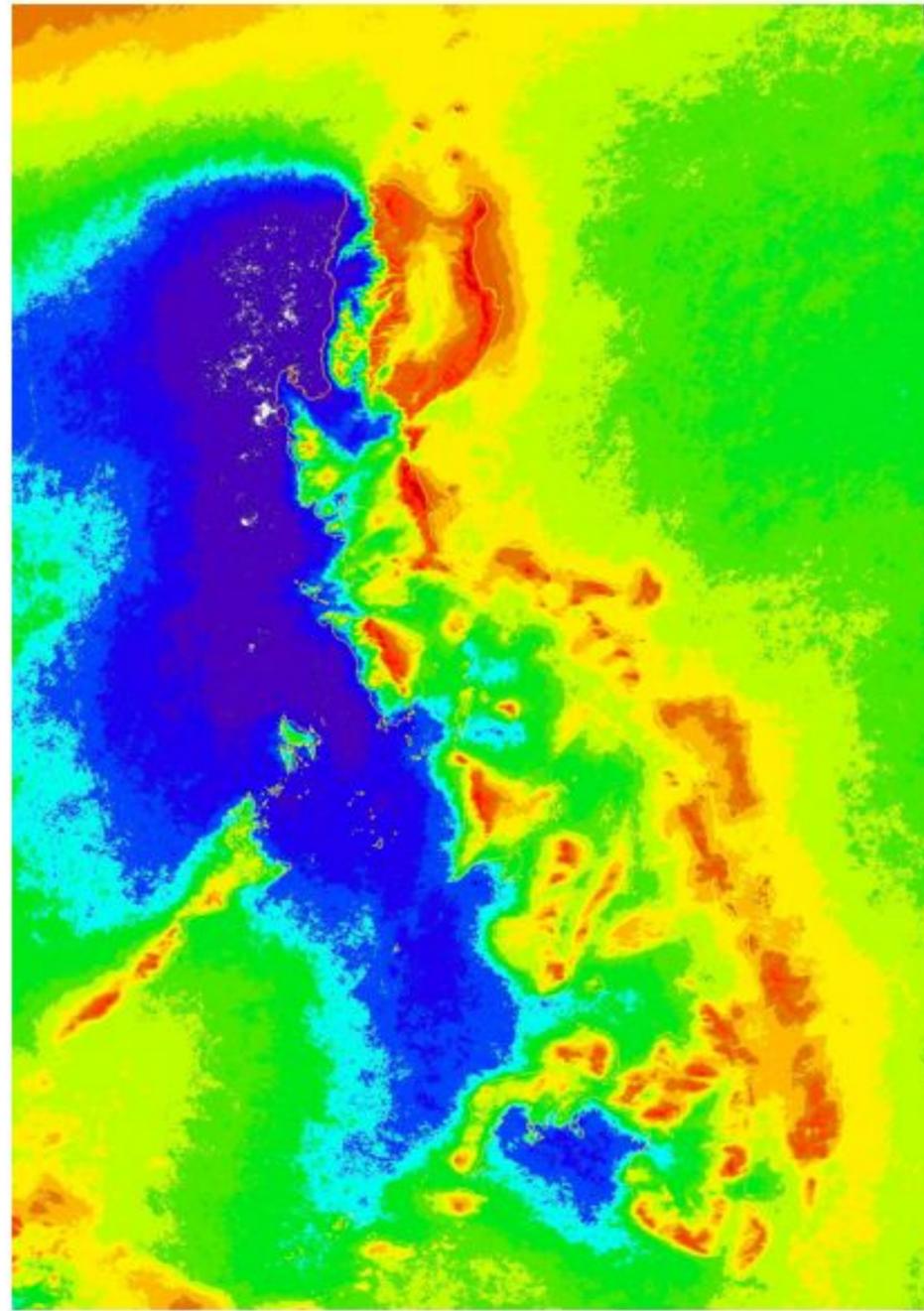


(Megahippus philippinensis)

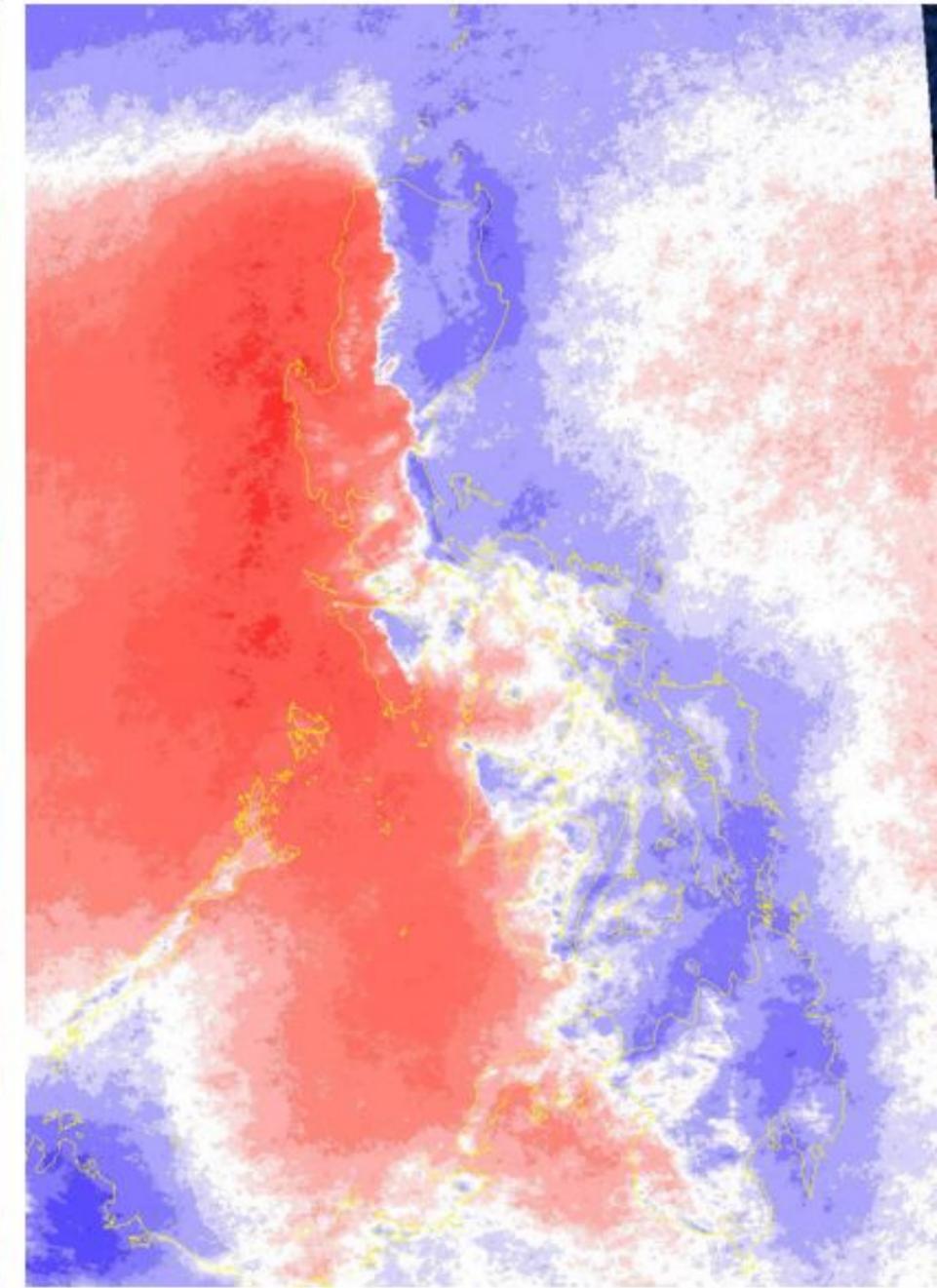
Seasonality derived from boreal summer and winter means



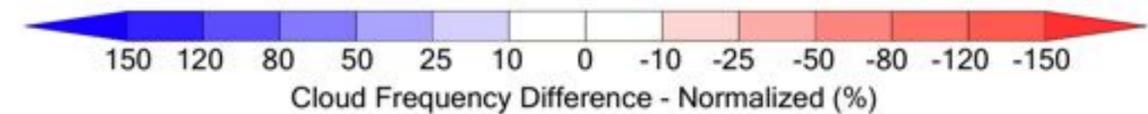
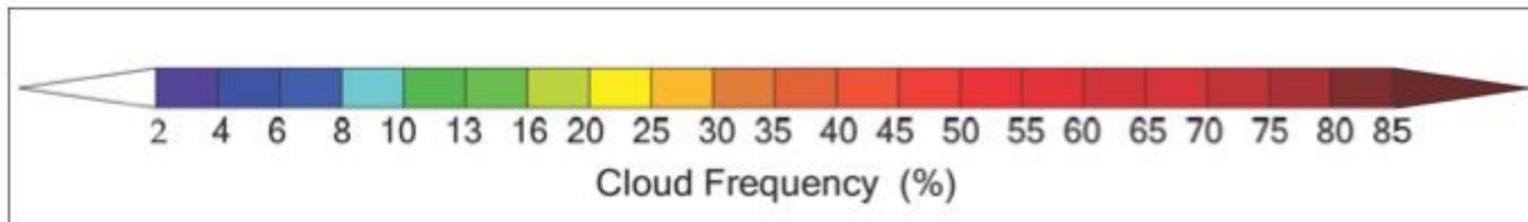
May-Oct mean
Terra+aqua



Nov-April mean
Terra+aqua



Normalized difference
Red is summer max
Blue is winter max



Happy 7 Billionth person Day!



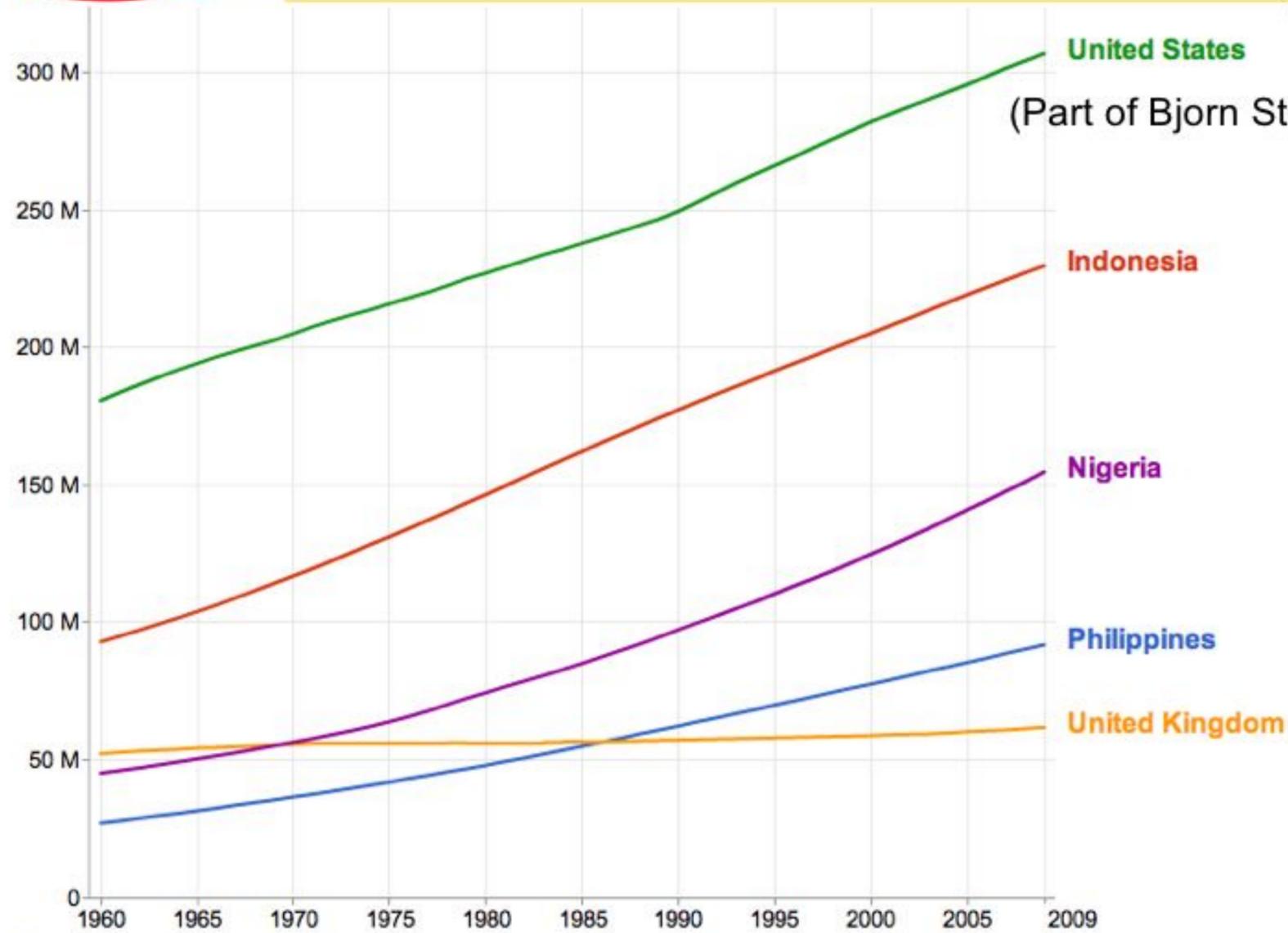
Compare Countries

Population

Climate Science's Greatest Challenge?

- Mauritania
- Mauritius
- Mayotte
- Mexico
- Micronesia, Fed. Sts.
- Moldova
- Monaco
- Mongolia
- Montenegro
- Morocco
- Mozambique
- Myanmar
- Namibia
- Nepal
- Netherlands
- Netherlands Antilles
- New Caledonia
- New Zealand
- Nicaragua
- Niger
- Nigeria
- Northern Mariana Islands
- Norway
- Oman
- Pakistan
- Palau

Clear selections



Data from: World Bank, World Development Indicators
Last updated: Jul 28, 2011

Show time settings

Population curves are following closely the better-known CO2 and global mean temperature curves...

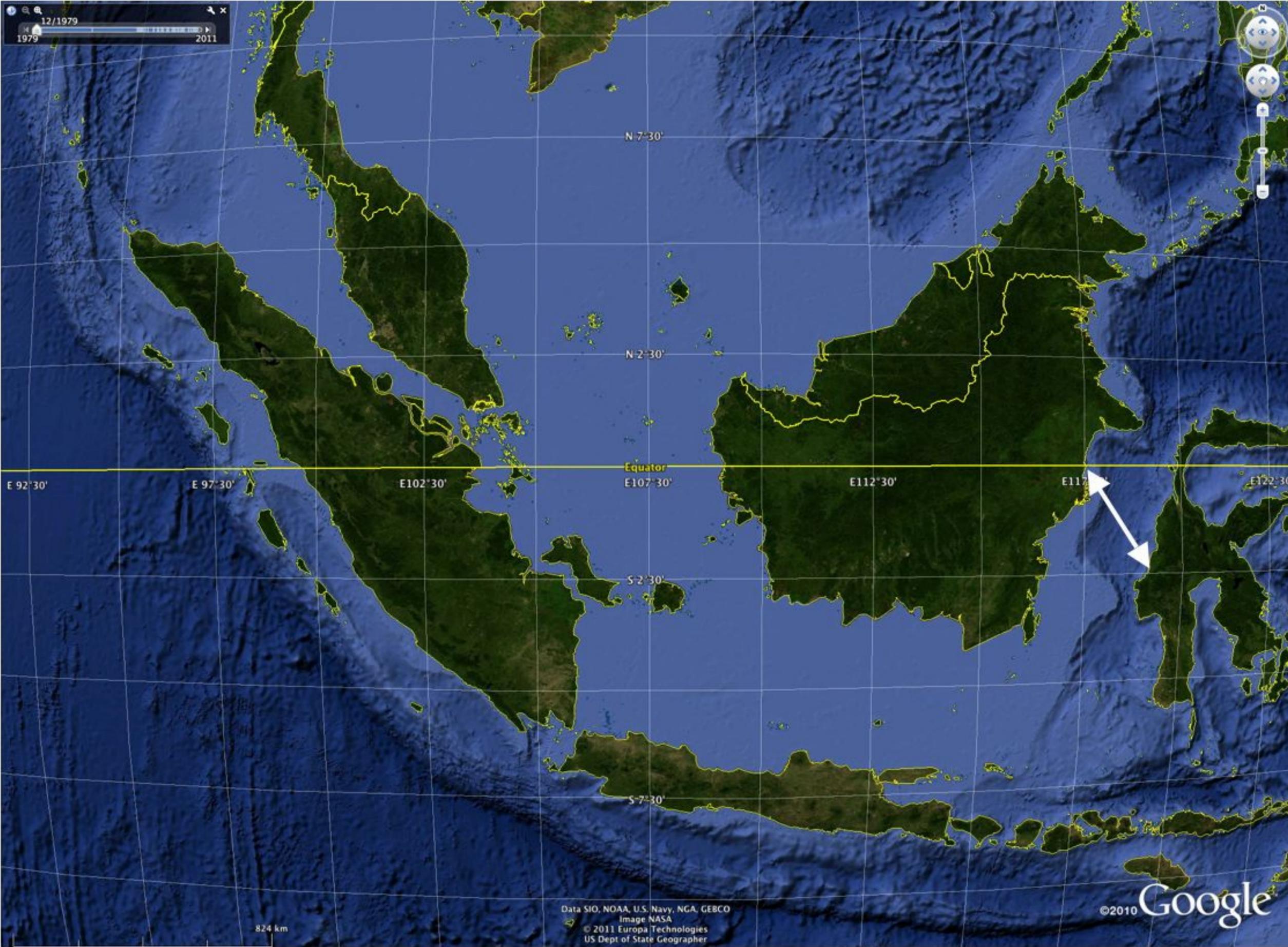
Is climate change driving the population rise?

Google: "Kalnay, population" for a perspective.

(Part of Bjorn Stevens's talk title)

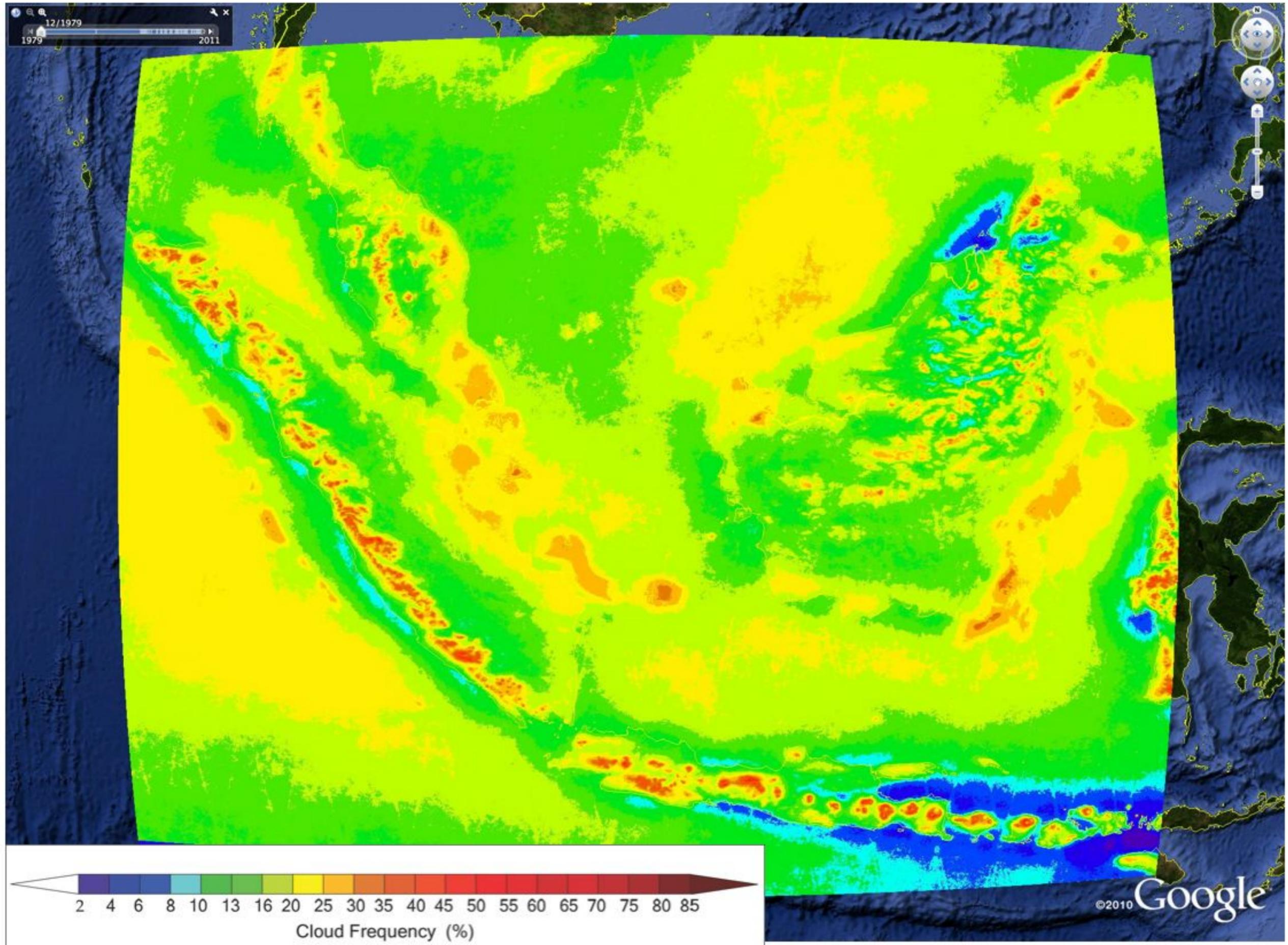


Forecast challenge: this region has ~ 300M people, straddles Equator.

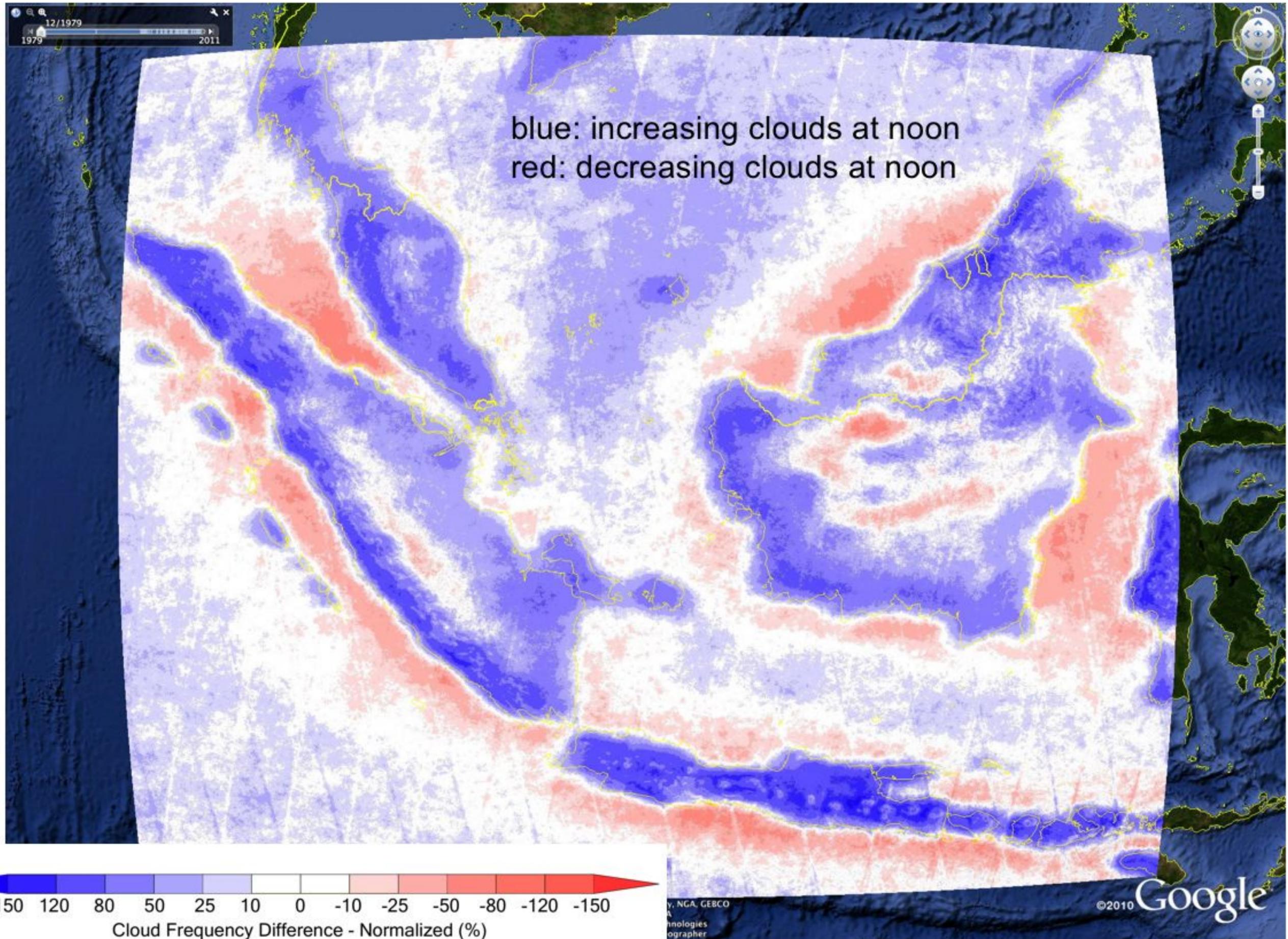


Annual mean daytime (Aqua+Terra) cloud frequency

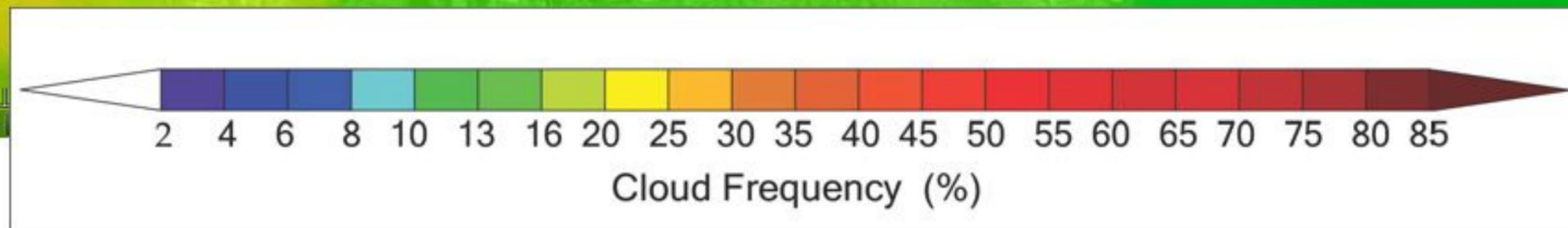
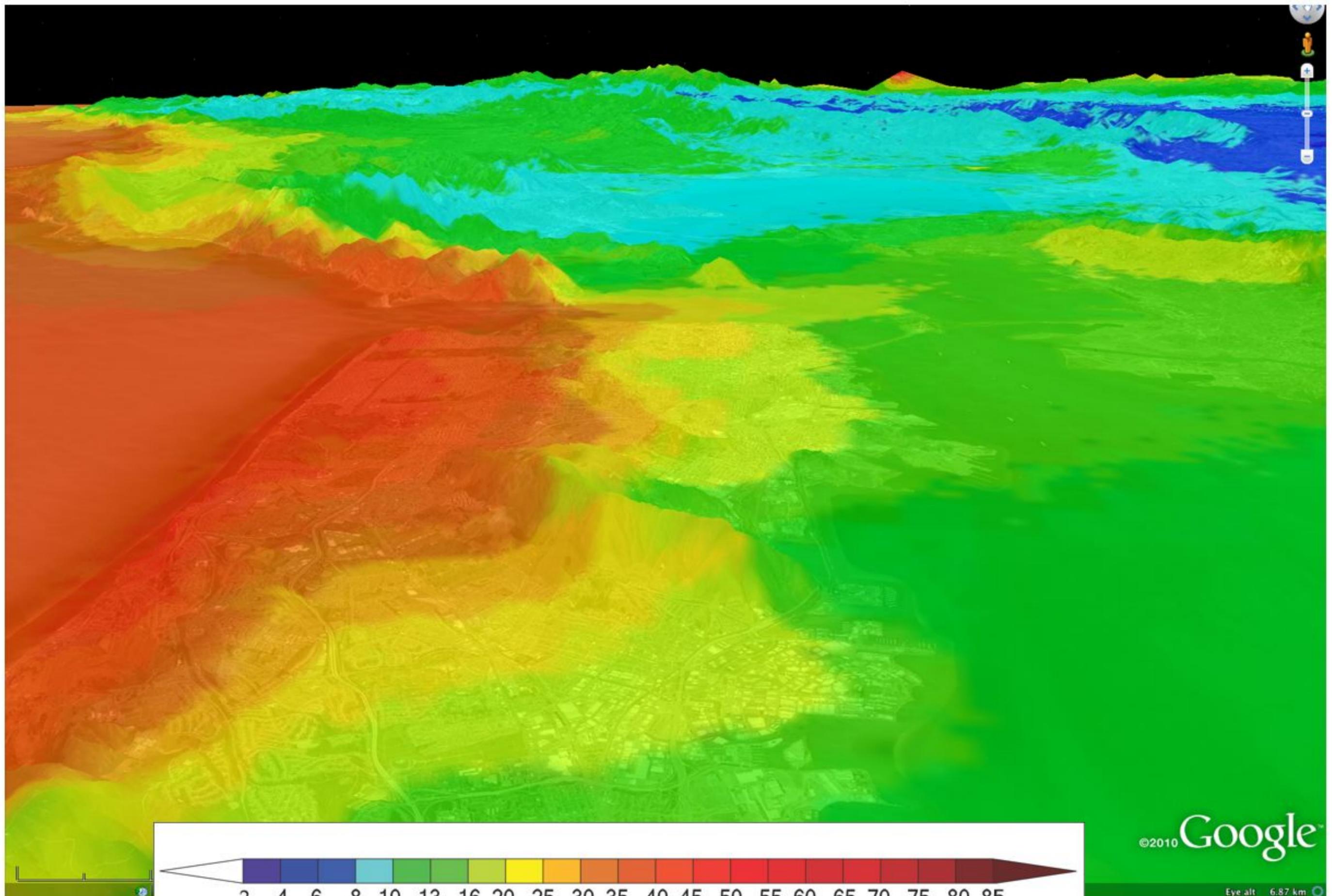
complicated, small-scale features

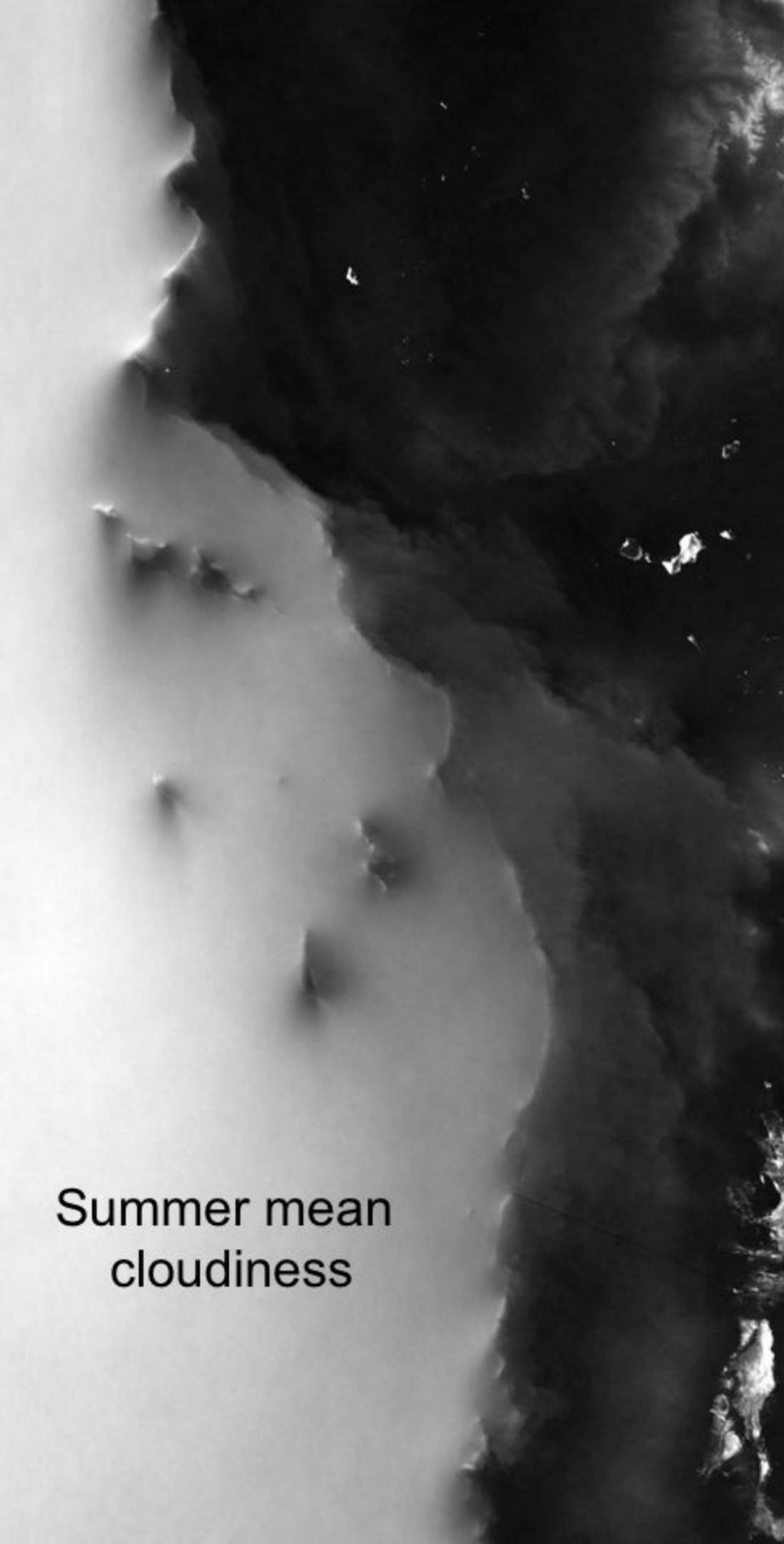


Practical applications: an aid to short-range forecasting (diurnal tendency over Indonesia/Malaysia)



June-August mean cloud frequency (aqua+terra)





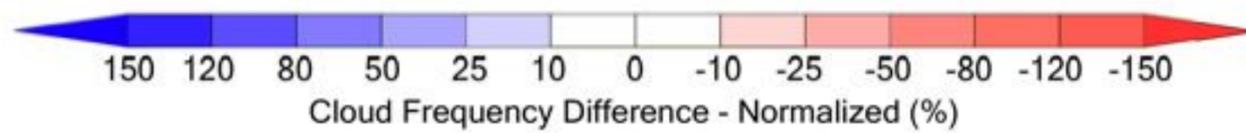
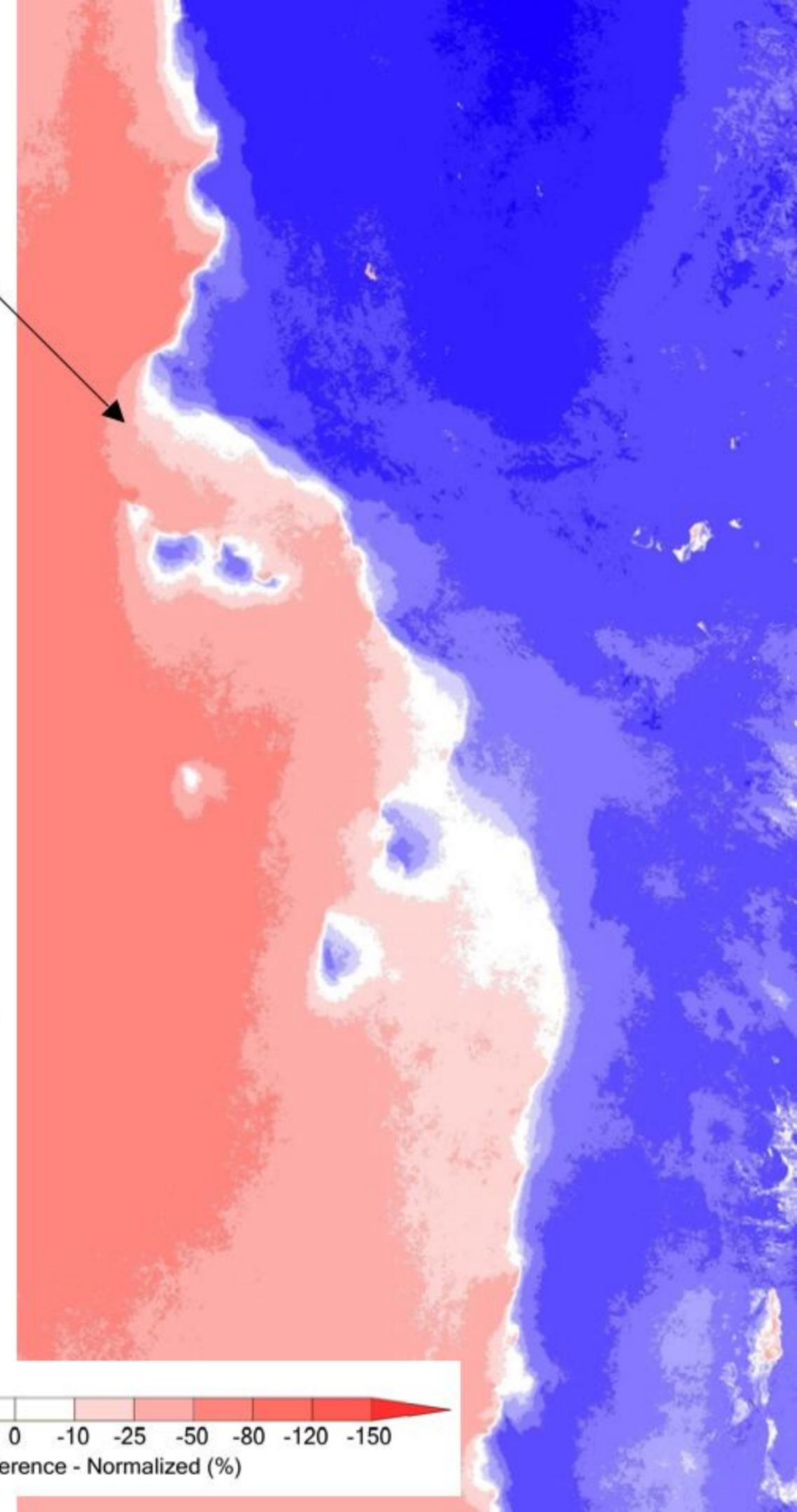
Summer mean cloudiness

Winter minus summer normalized cloudiness

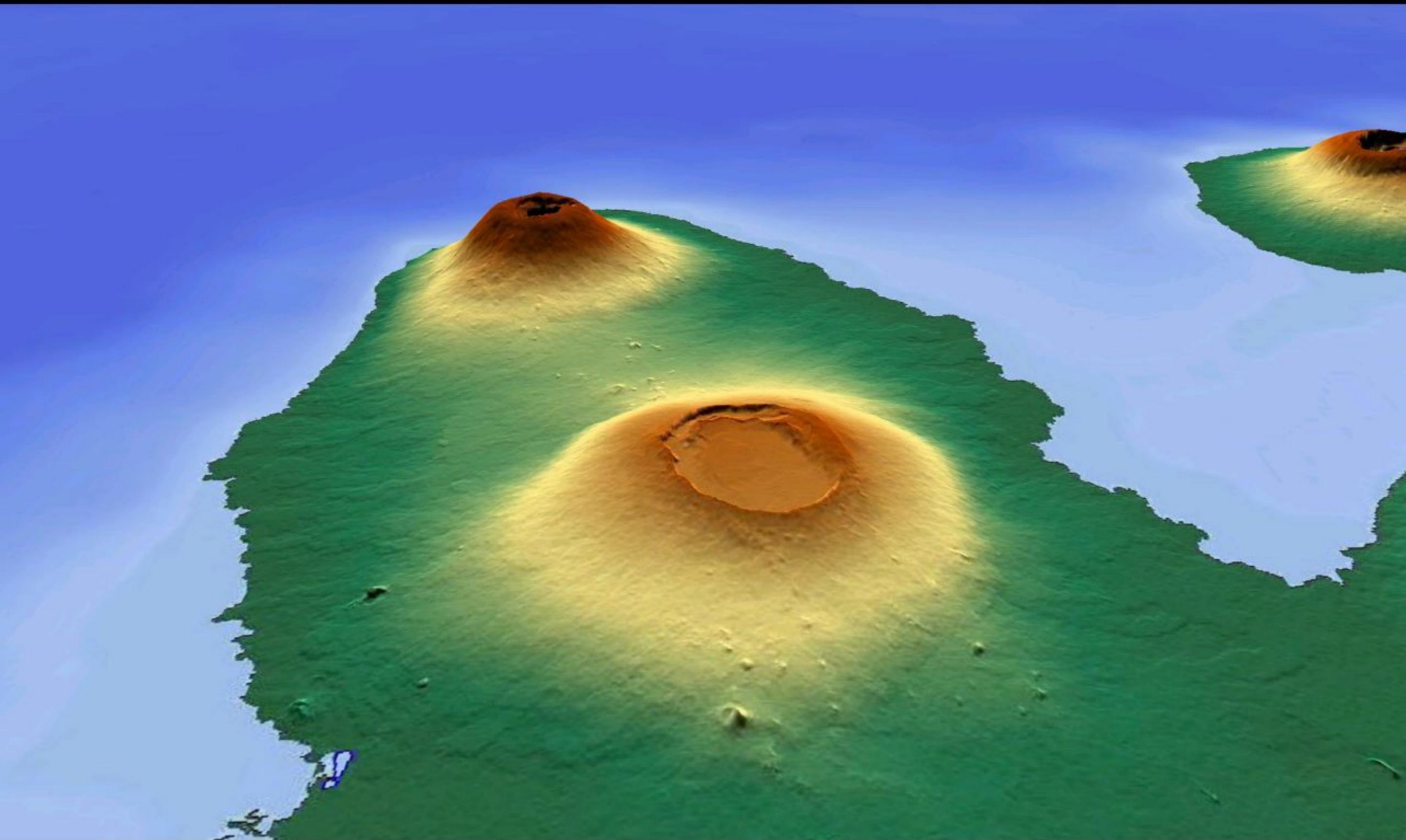
(red is summer max)

Who might find this useful?

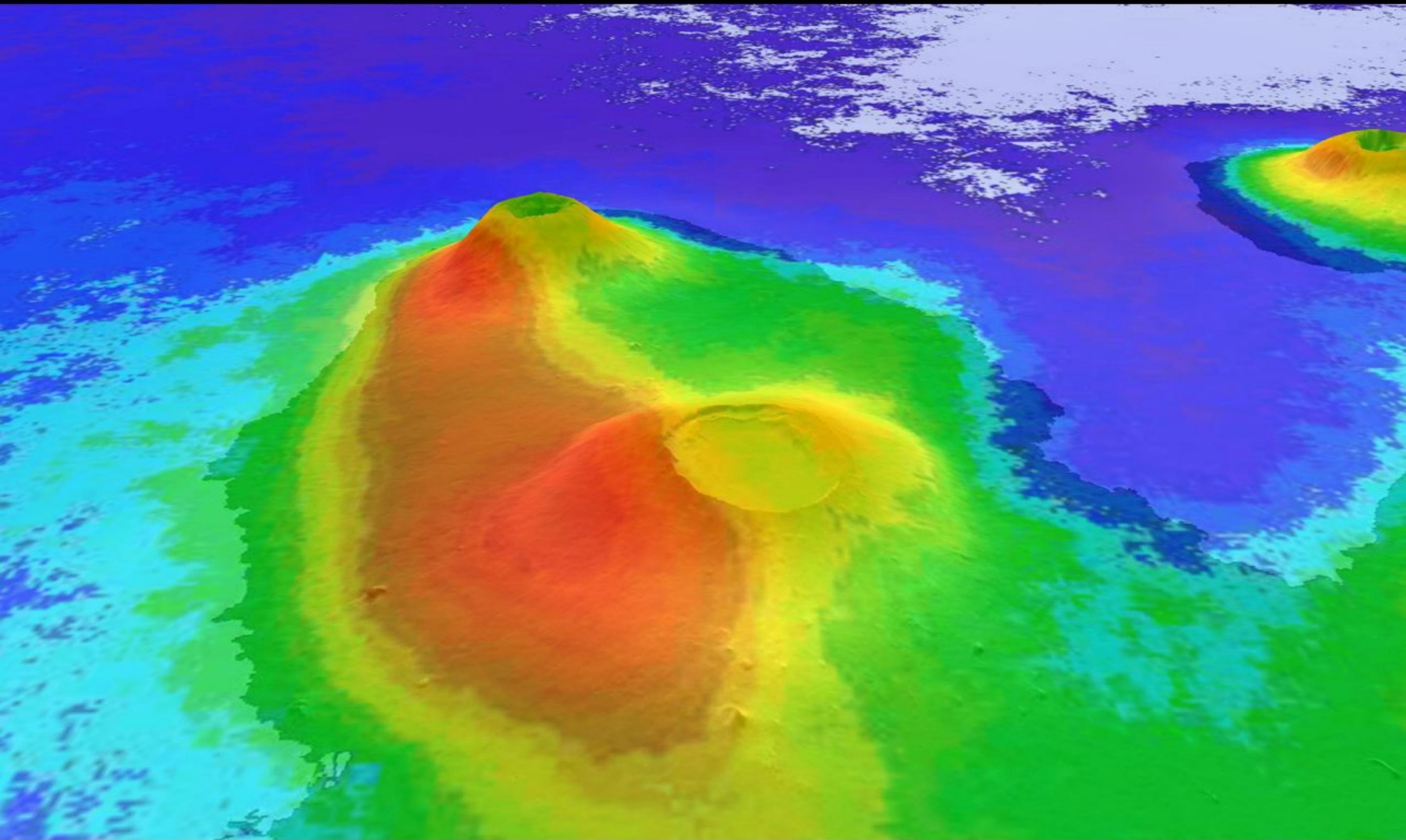
Is this high-impact weather?



Part of Isabella Island, Galapagos, view west



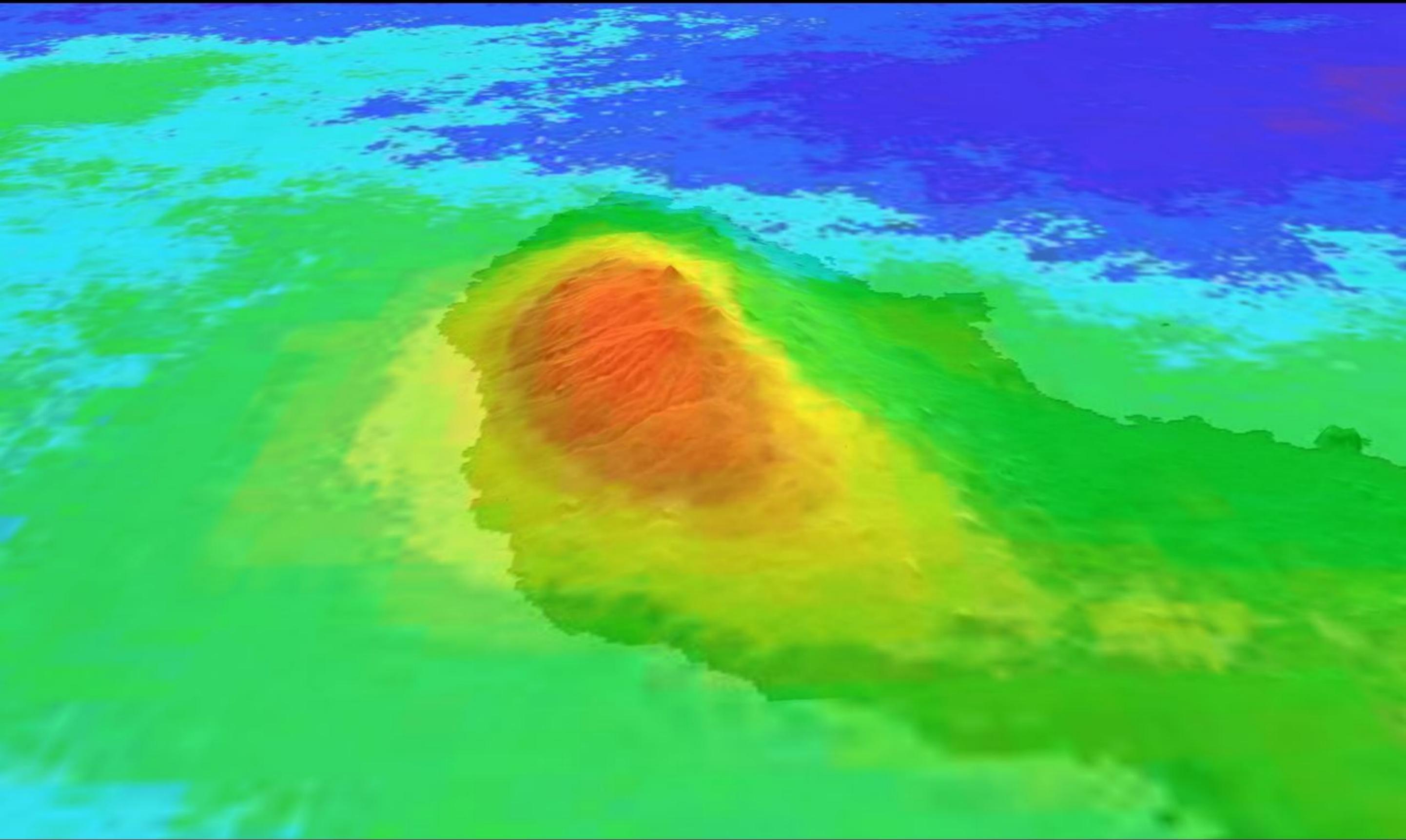
Mean annual cloudiness

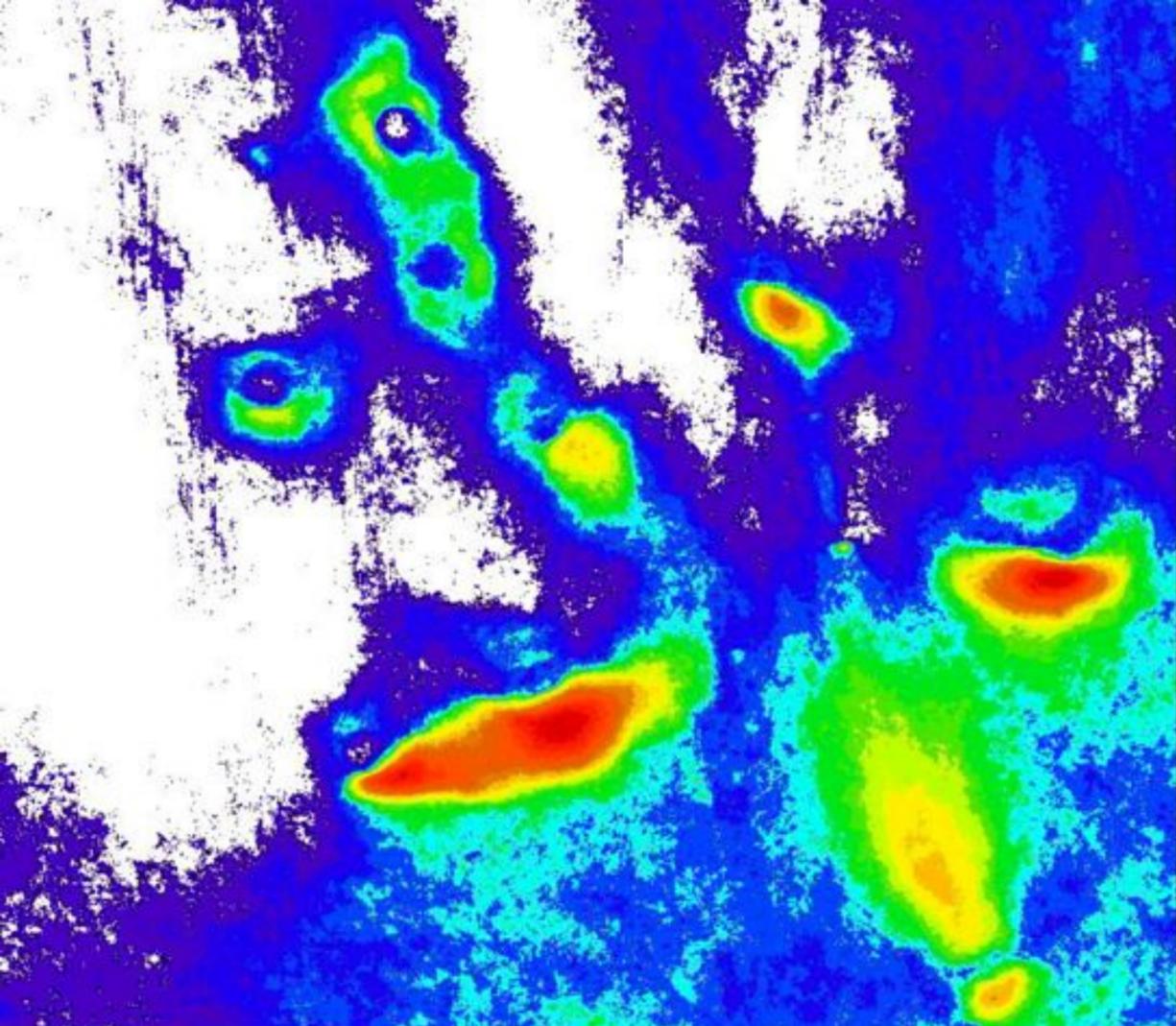


San Cristobal Island, site of US-funded GCOS raob site

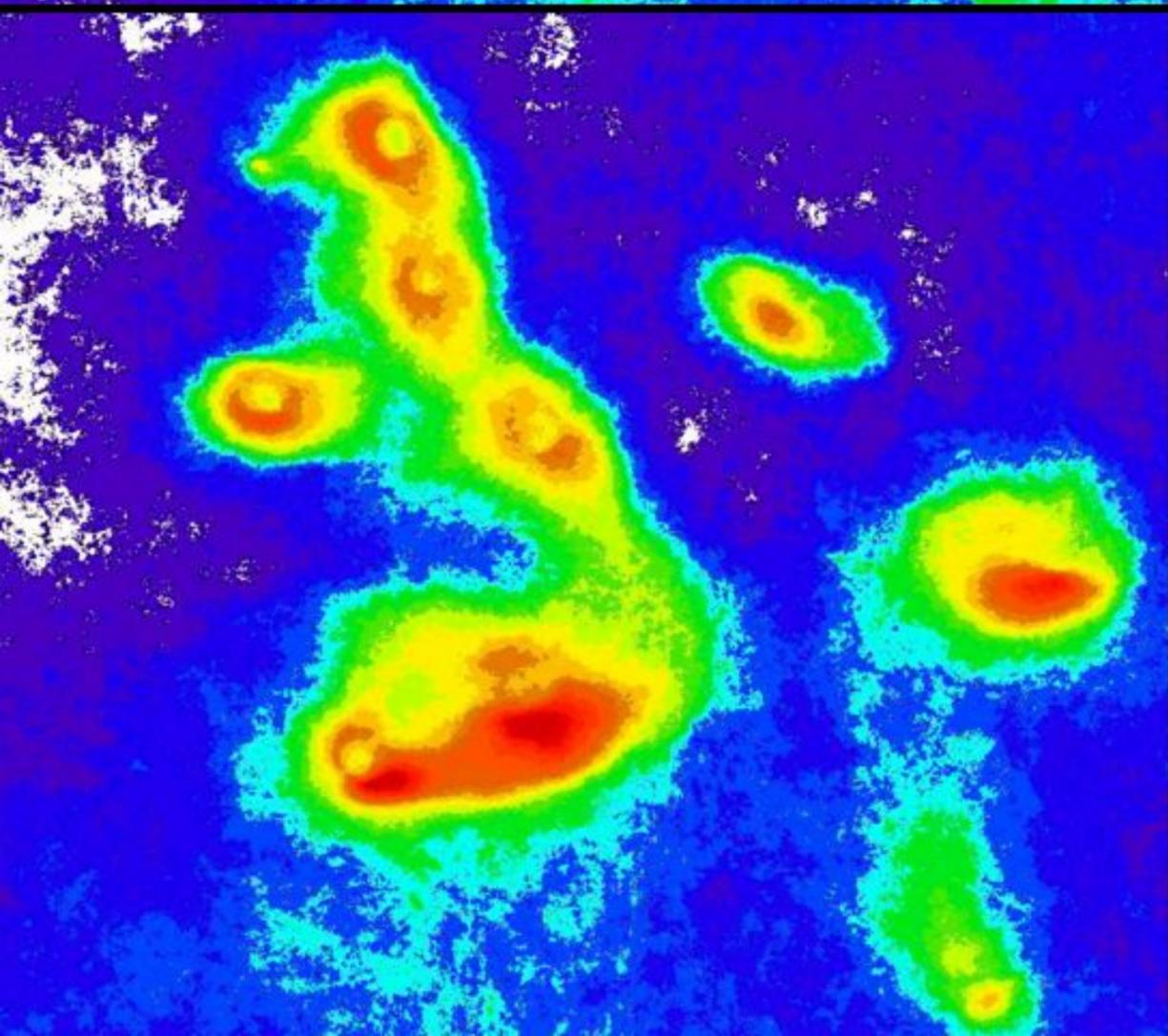
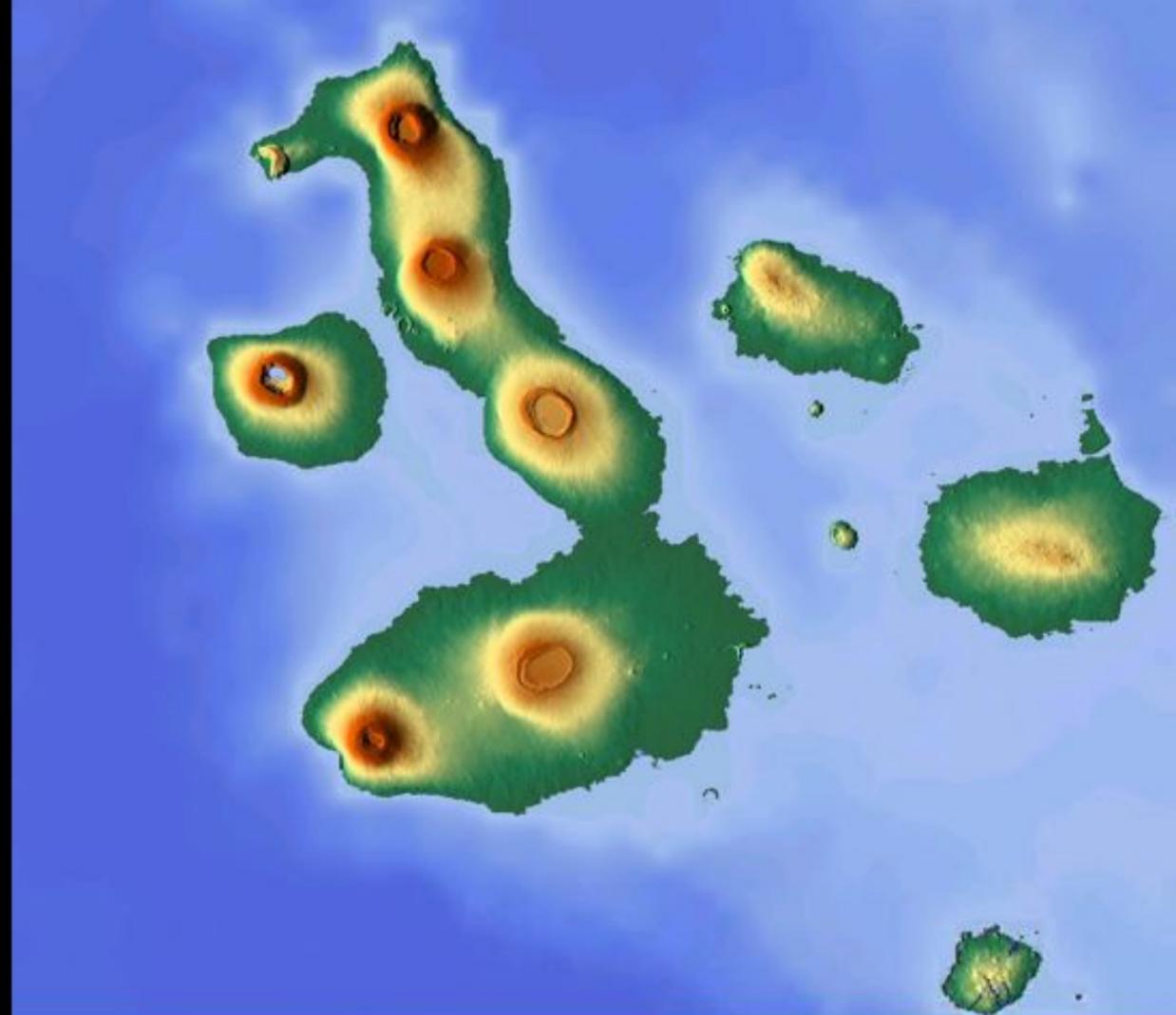


Highest ~600m

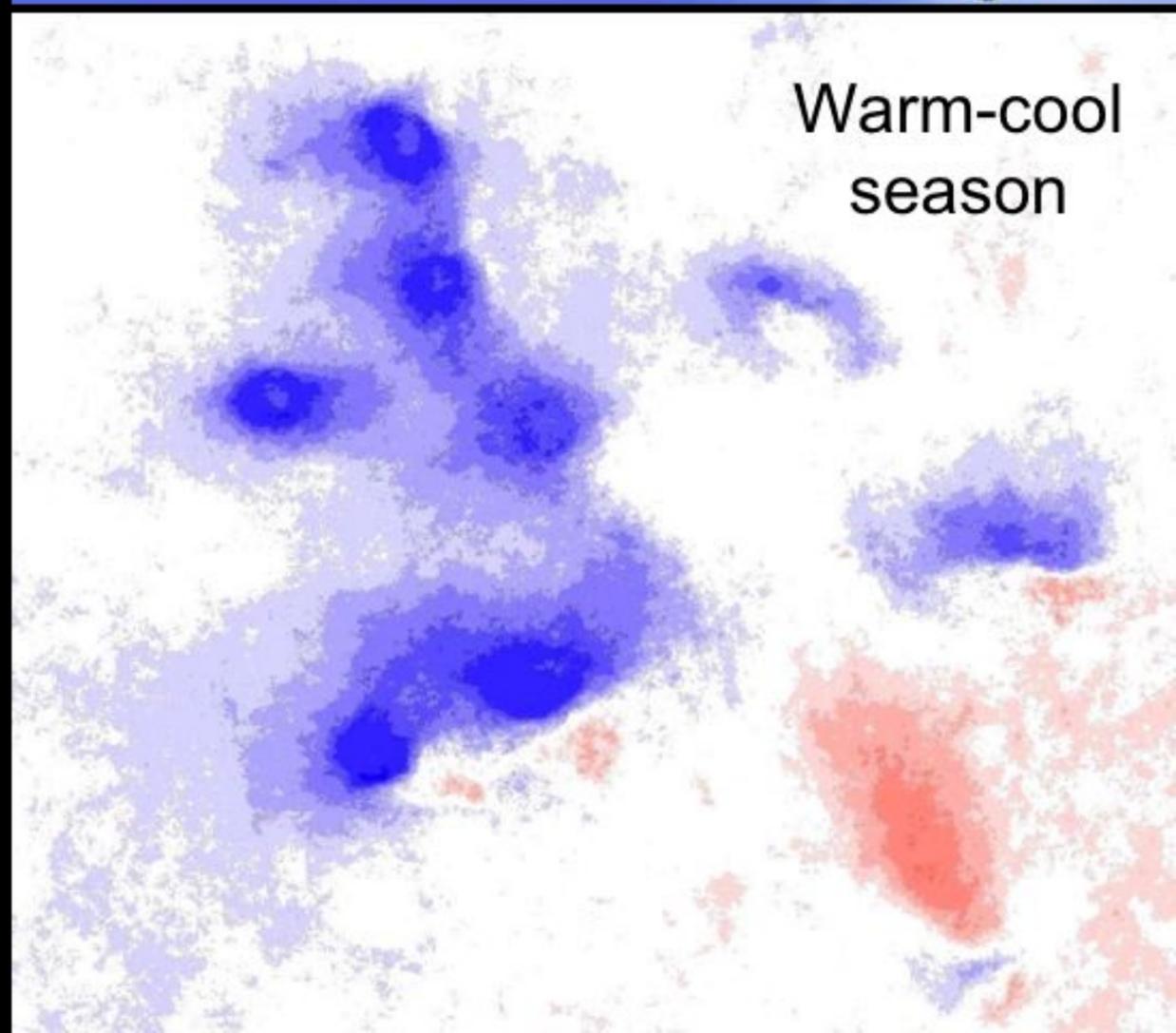




cool
season
(05-10)



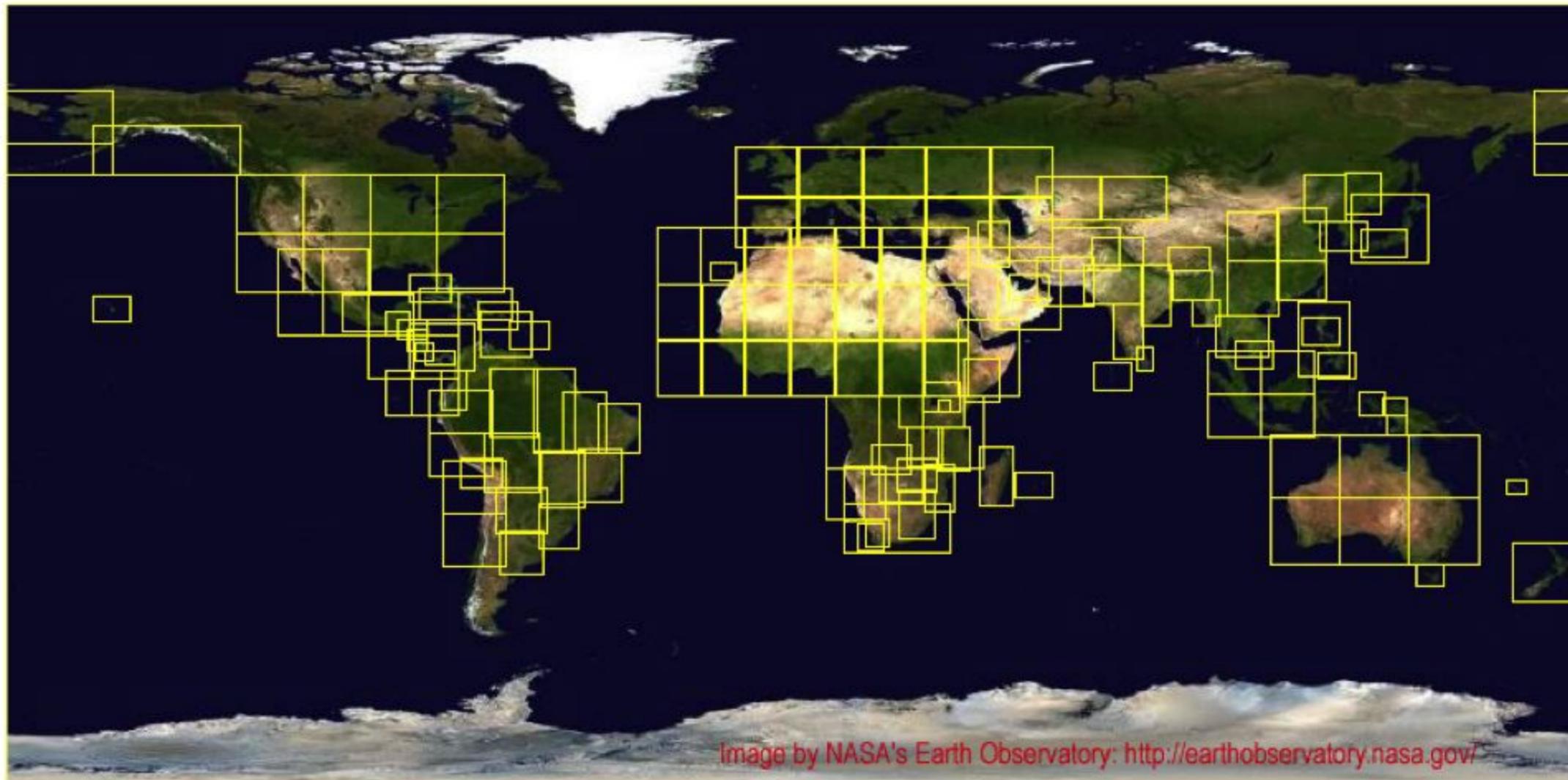
warm
season
(11-04)



Warm-cool
season

We wanted global coverage to provide “context” for our over-land 250 m cloud climatologies

- Global daily mosaics available from NASA web site(s).
- use same procedure as with full res'n imagery to obtain “similar” results...



NASA website source of imagery

[NASA Earth Data](#) | [Data Discovery](#) | [Data Centers](#) | [Community](#) | [Science Disciplines](#) | [Search EOSDIS](#)

 **National Aeronautics and Space Administration**
LANCE



Search

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Rapid Response

Welcome to the new Rapid Response system, now part of NASA's [Land Atmosphere Near Real-time Capability for EOS \(LANCE\)](#). Rapid Response provides daily MODIS images in near real time presented by [geographic regions \("subsets"\)](#) or [orbit overpass time \("realtime"\)](#). We are also developing an interactive [Web Mapping Service \(WMS\)](#) which includes imagery from MODIS and other instruments.

Contact Jeff.Schmaltz@nasa.gov with any questions.

Images

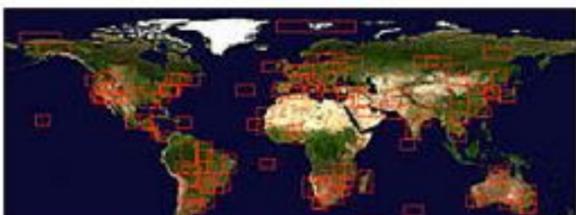
Web Mapping Service (WMS)

View and download imagery from a variety of EOS remote sensing products using the interactive Web Mapping Service (WMS). Multiple products from multiple instruments can be overlaid with population density data and administrative boundaries from the [Socioeconomic Data and Applications Center \(SEDAC\)](#). An [Antarctic Polar WMS](#) and an [Arctic Polar WMS](#) are available using the polar stereographic coordinate system to assist in viewing high/low latitude phenomena. **NOTE: The WMS currently does not work with Internet Explorer. We are investigating this issue and hope to have it resolved soon.**



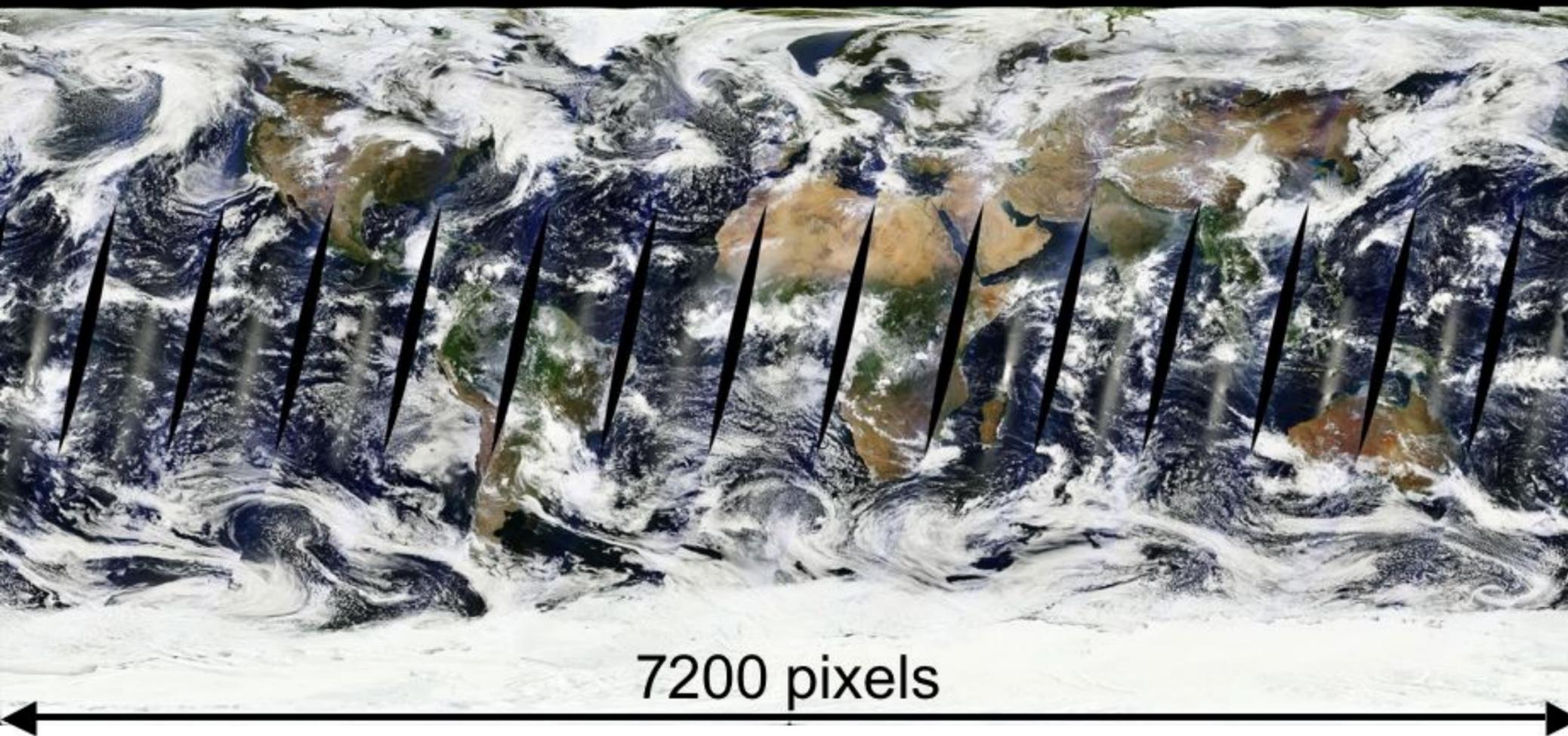
Subsets

A large number of geo-rectified images across the world are available in GIS-compatible format. The subsets are user-specified and include most of the AERONET sunphotometer sites. To add additional



Rapid Response

- [Web Mapping Service \(WMS\)](#)
- [Subsets](#)
- [Near Real Time \(Orbit Swath\) Images](#)
- [Gallery](#)
- [Antarctica Mosaic](#)
- [Arctic Mosaic](#)
- [Global Fire Maps](#)
- [System Status](#)
- [Frequently Asked Questions \(FAQ\)](#)



MODIS "true-color" imagery from two NASA satellites

Terra ~1030 LT
daytime imagery



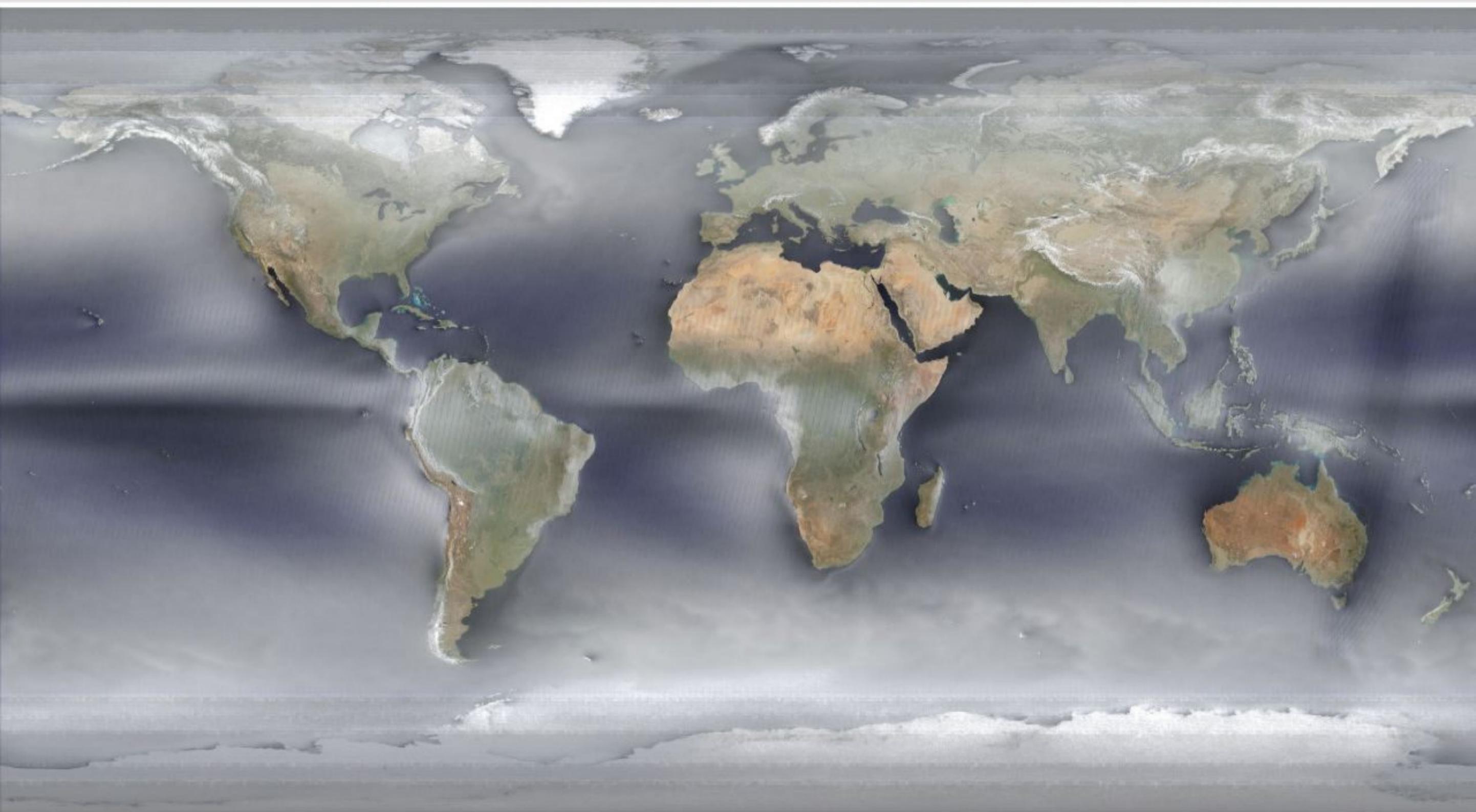
Aqua ~1330 LT
daytime imagery

NASA website had disclaimer that “The global browse images are meant to provide a quick look ... and... should not be used for scientific analysis.”...

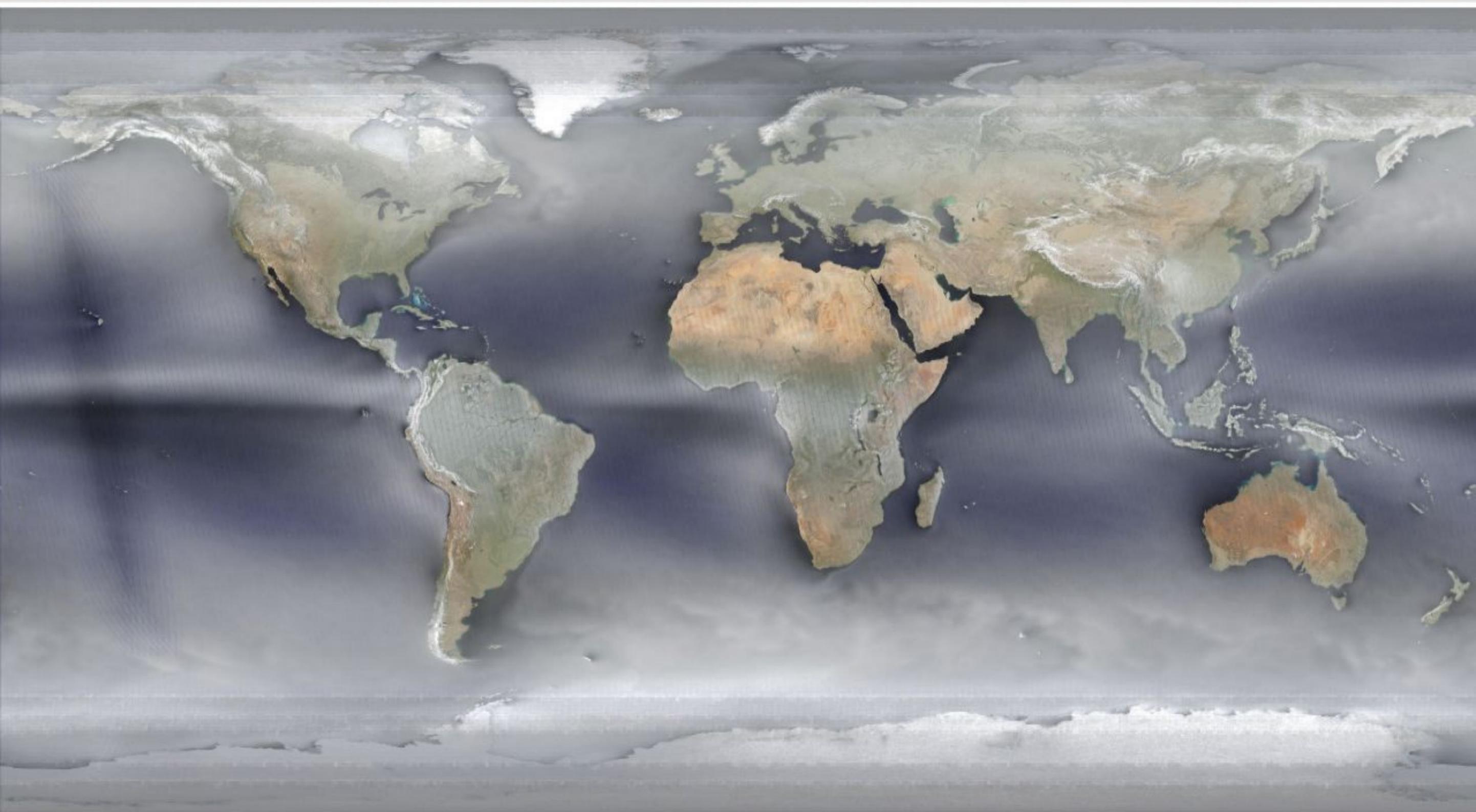
... we proceeded anyway

(ask me sometime why I am skeptical about complex algorithms and “quality controlled” or “quality-assured” products)

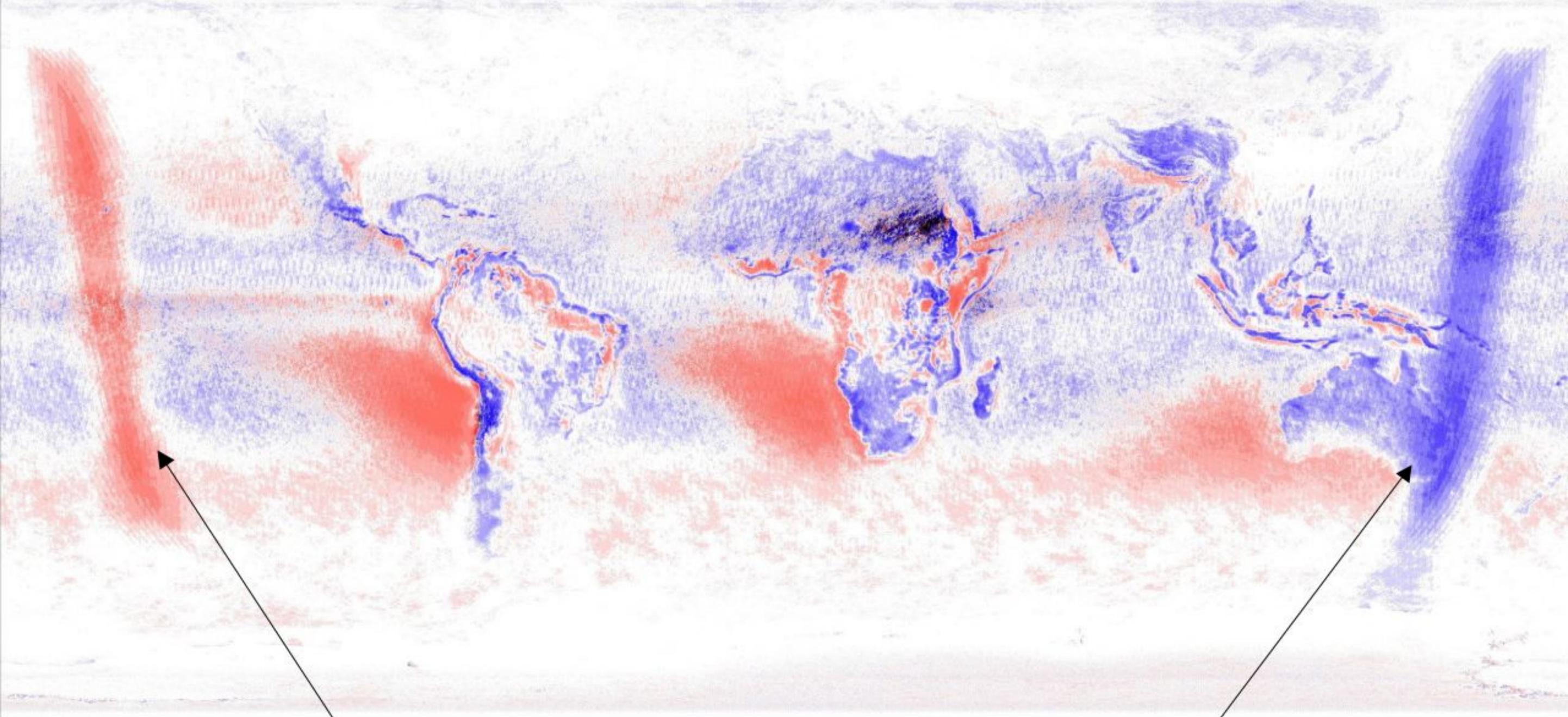
Mean Terra “true color” images (~1030 LT)



Mean Aqua “true color” images (1330 LT)

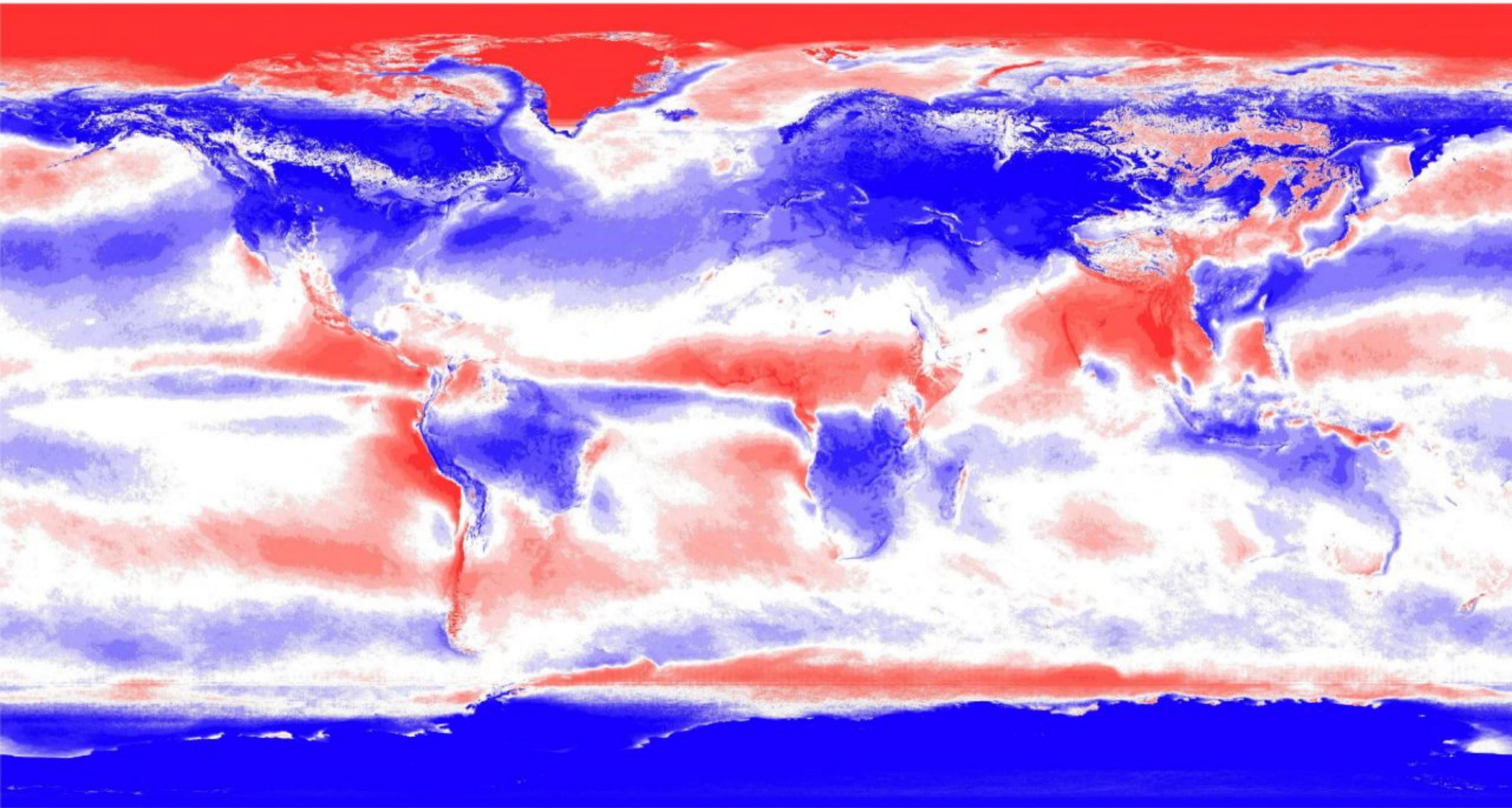


Why they say this isn't for scientific research: Aqua-terra mean, normalized by mean cloudiness, red is decreasing, blue increasing, during mid-day

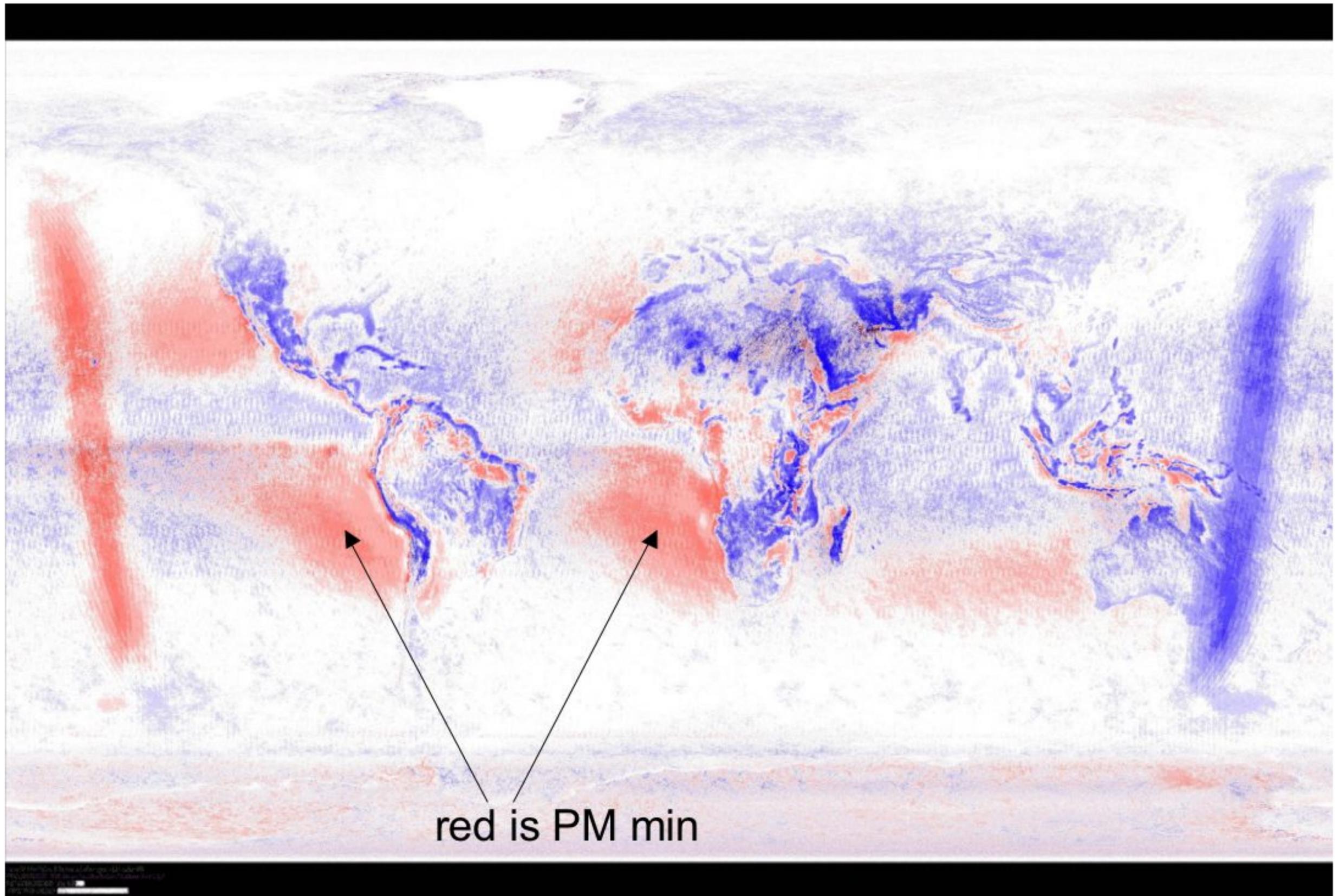


Artifacts of global mosaic generation

Seasonality; summer-winter (red is boreal summer cloud max)

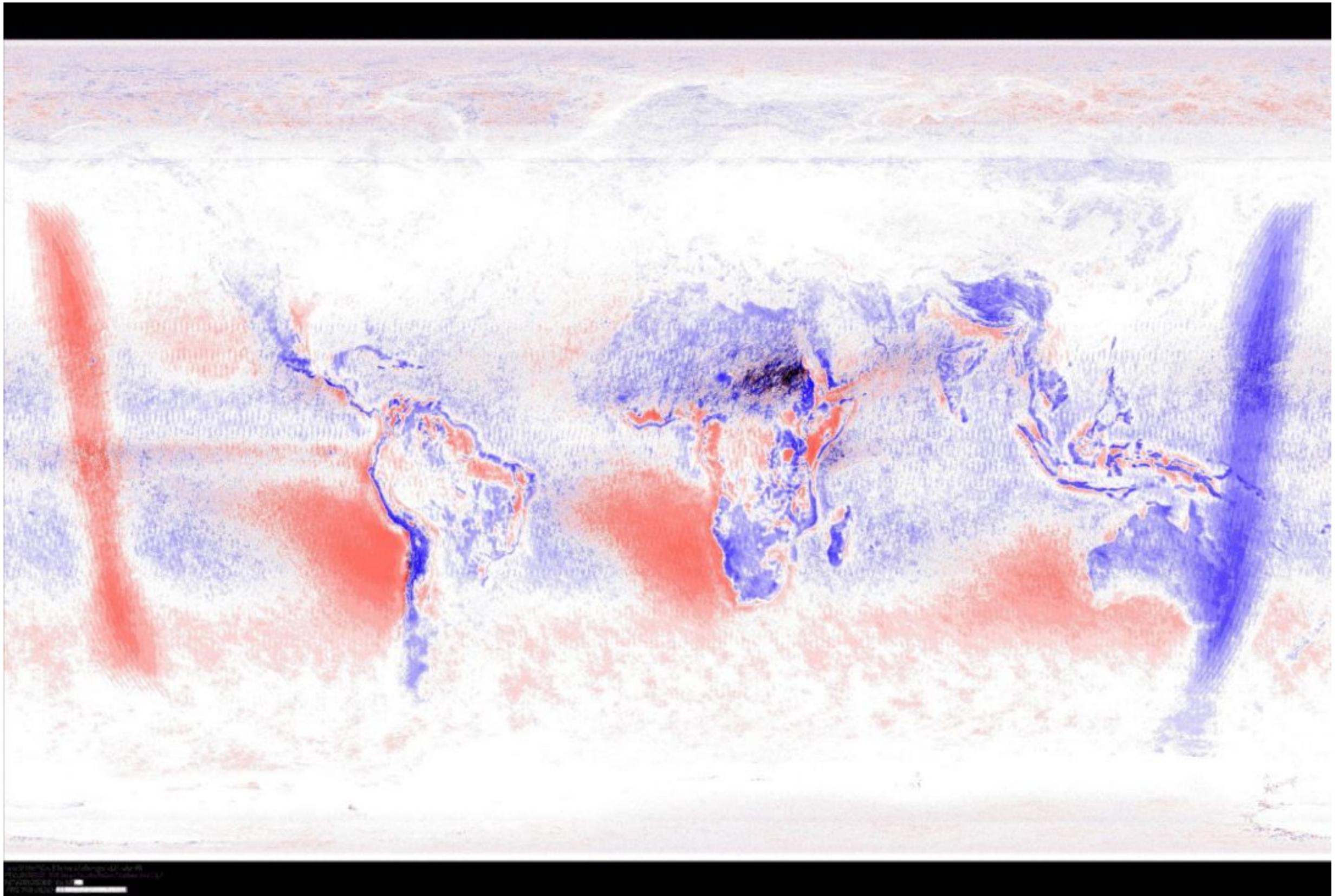


Seasonality of “diurnal variation”; normalized aqua-terra



May-Oct

Note small diurnal variation at high latitudes, larger in warm hemisphere



Nov-Apr

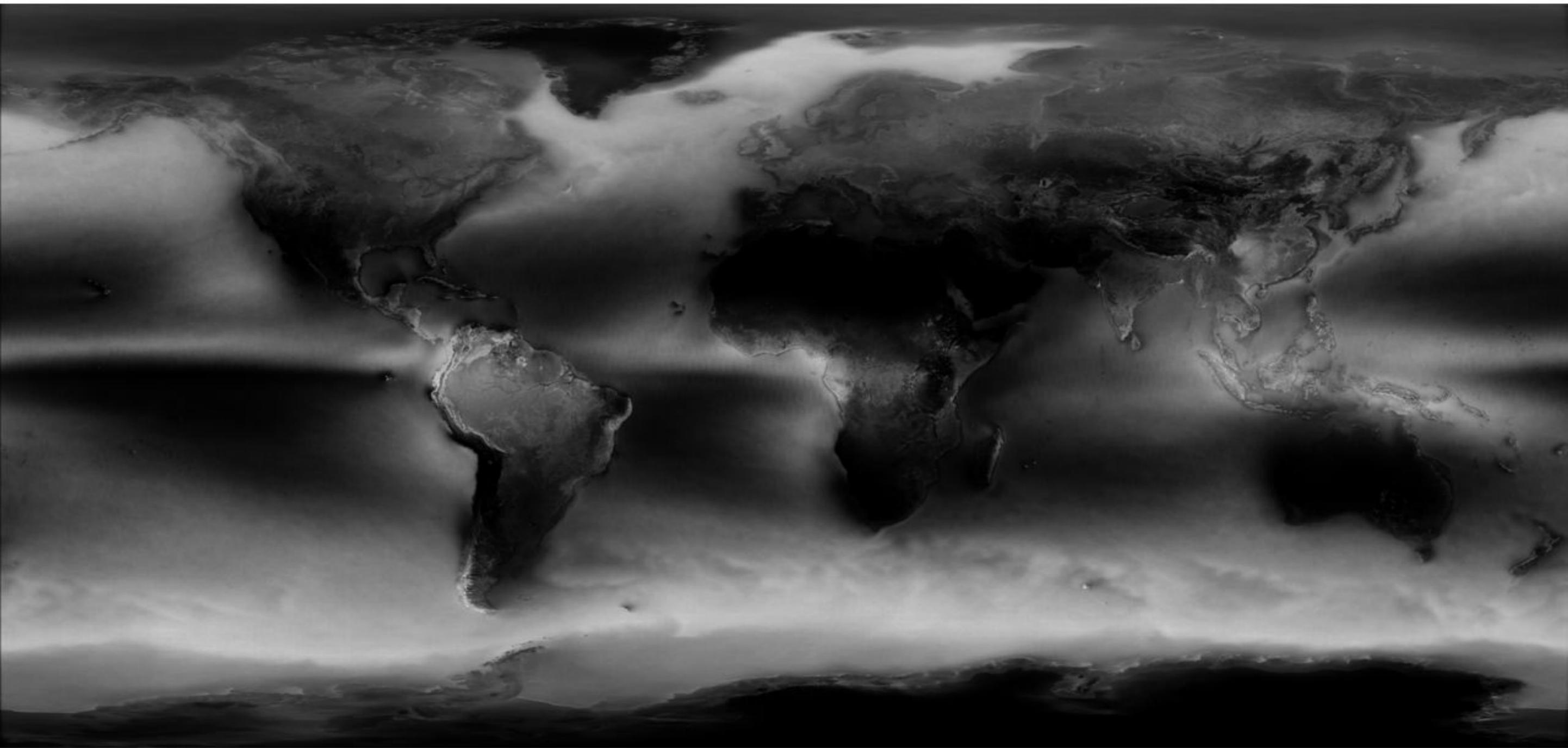
Key focus of this talk...

~ 8 year mean (Aqua+Terra) using our thresholding procedure



(grayscale = brighter is higher frequency of clouds)

Using NASA Quick-look data: <http://neo.sci.gsfc.nasa.gov>
(this product has problems - more for flagging possible contamination rather than identifying cloudy pixels)

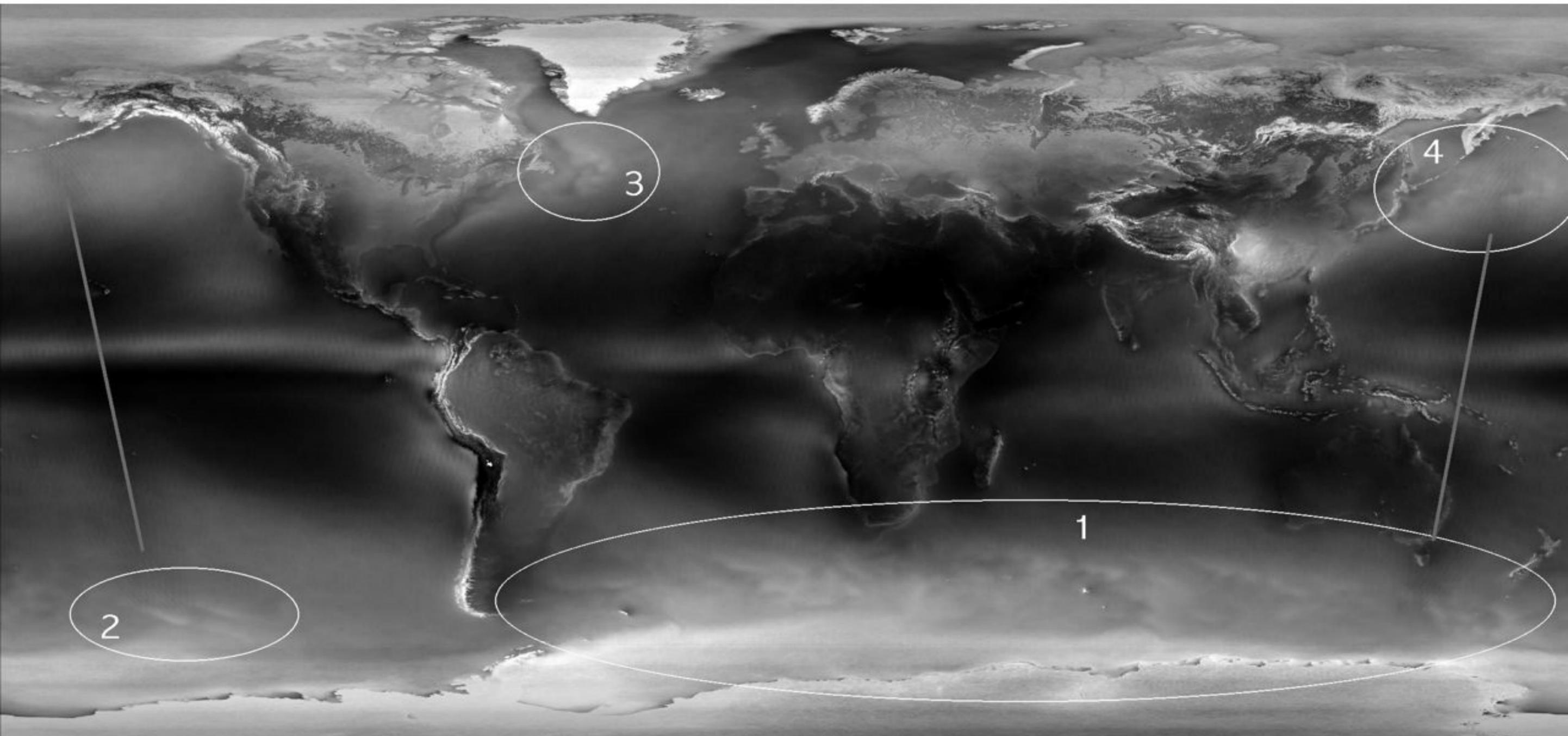


Annual mean cloud fraction product (Aqua+Terra)

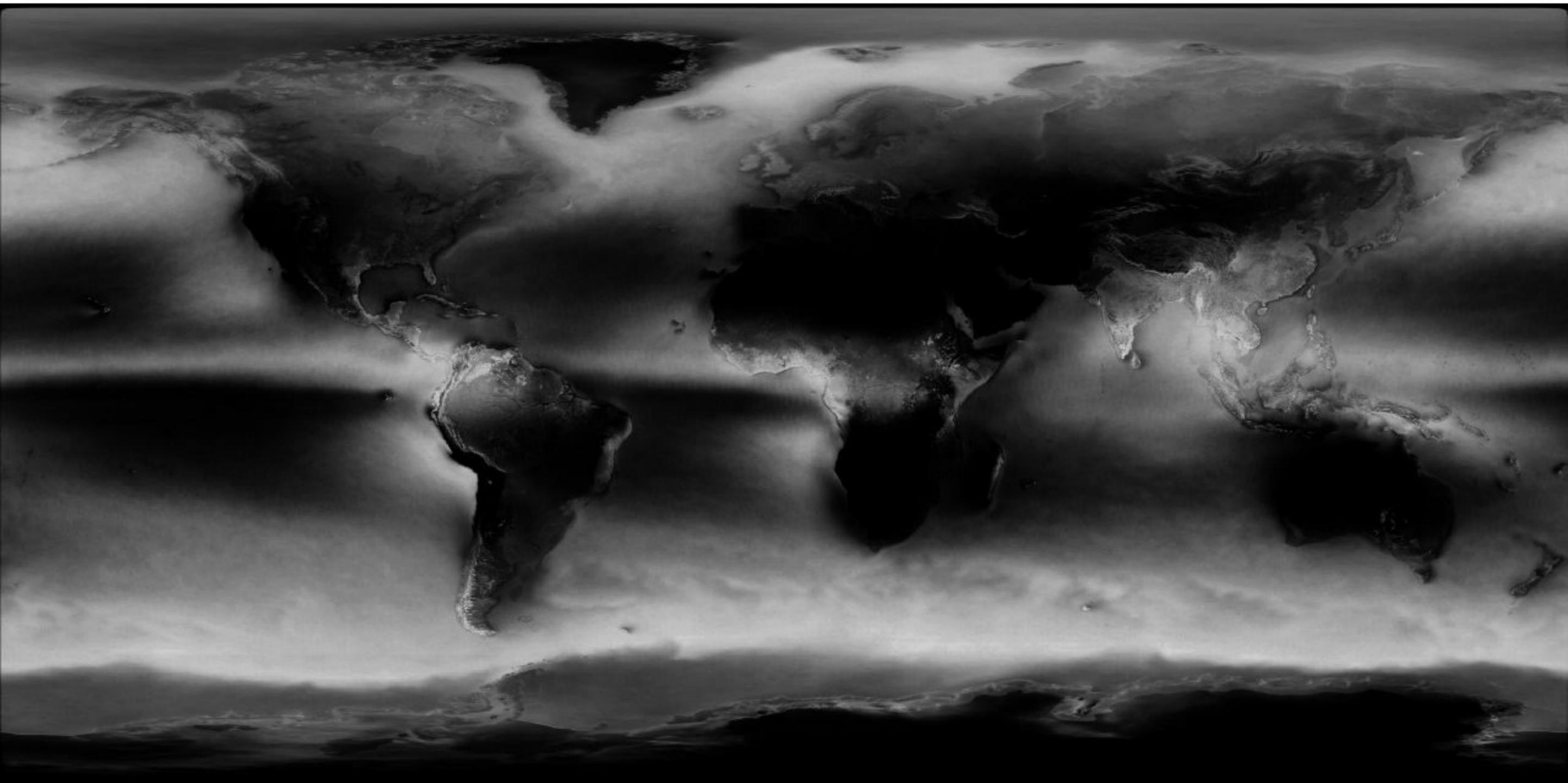
In summary, the surprising features are:

Large spatial variability of mean cloudiness in 4 regions:

- *Antarctic circumpolar current (1 and 2)*
- *Grand Banks (3)*
- *Kuroshio extension (4)*



Boreal summer (May-October)

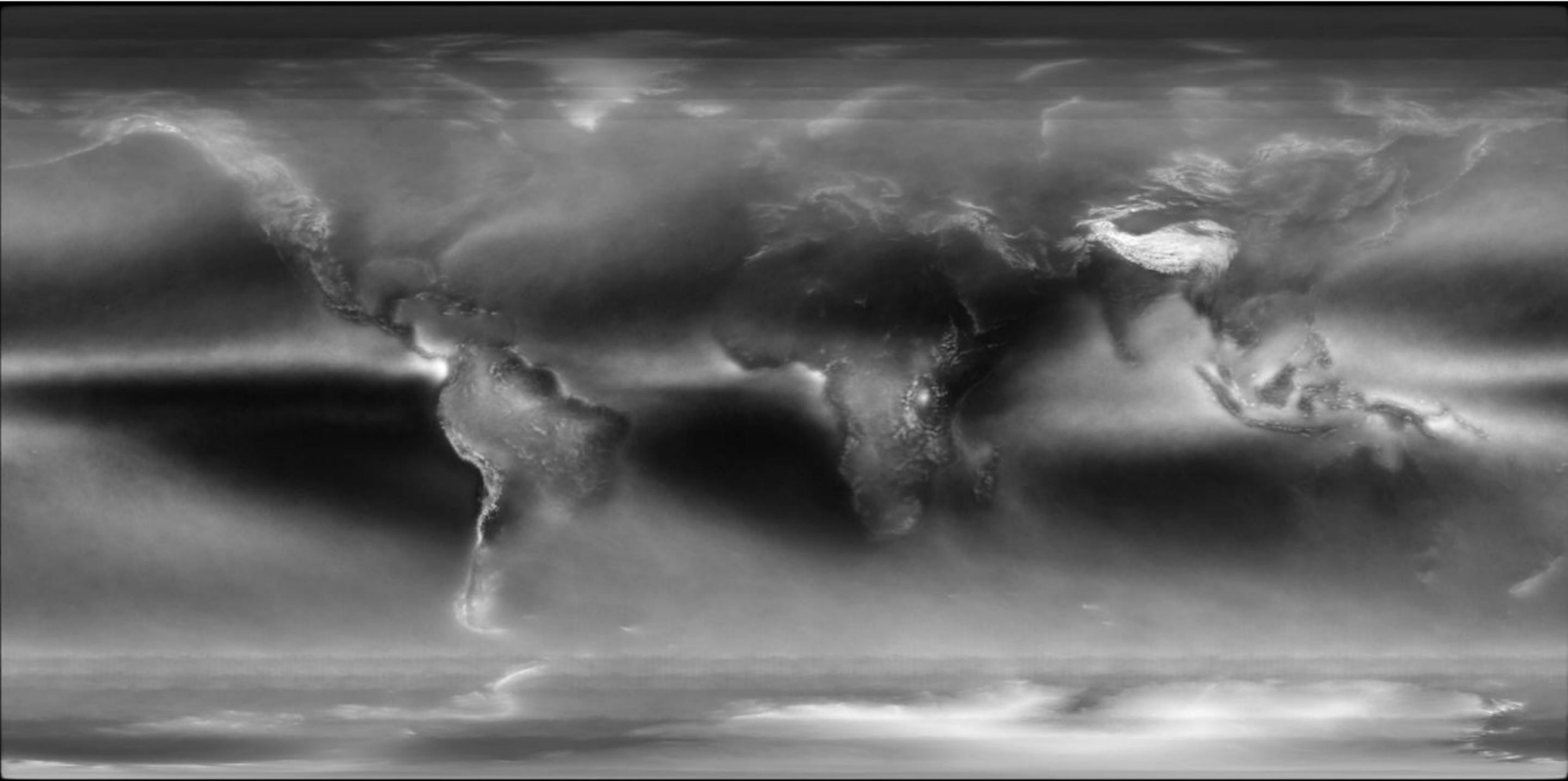


Boreal winter (Nov-April)



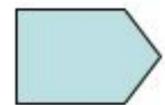
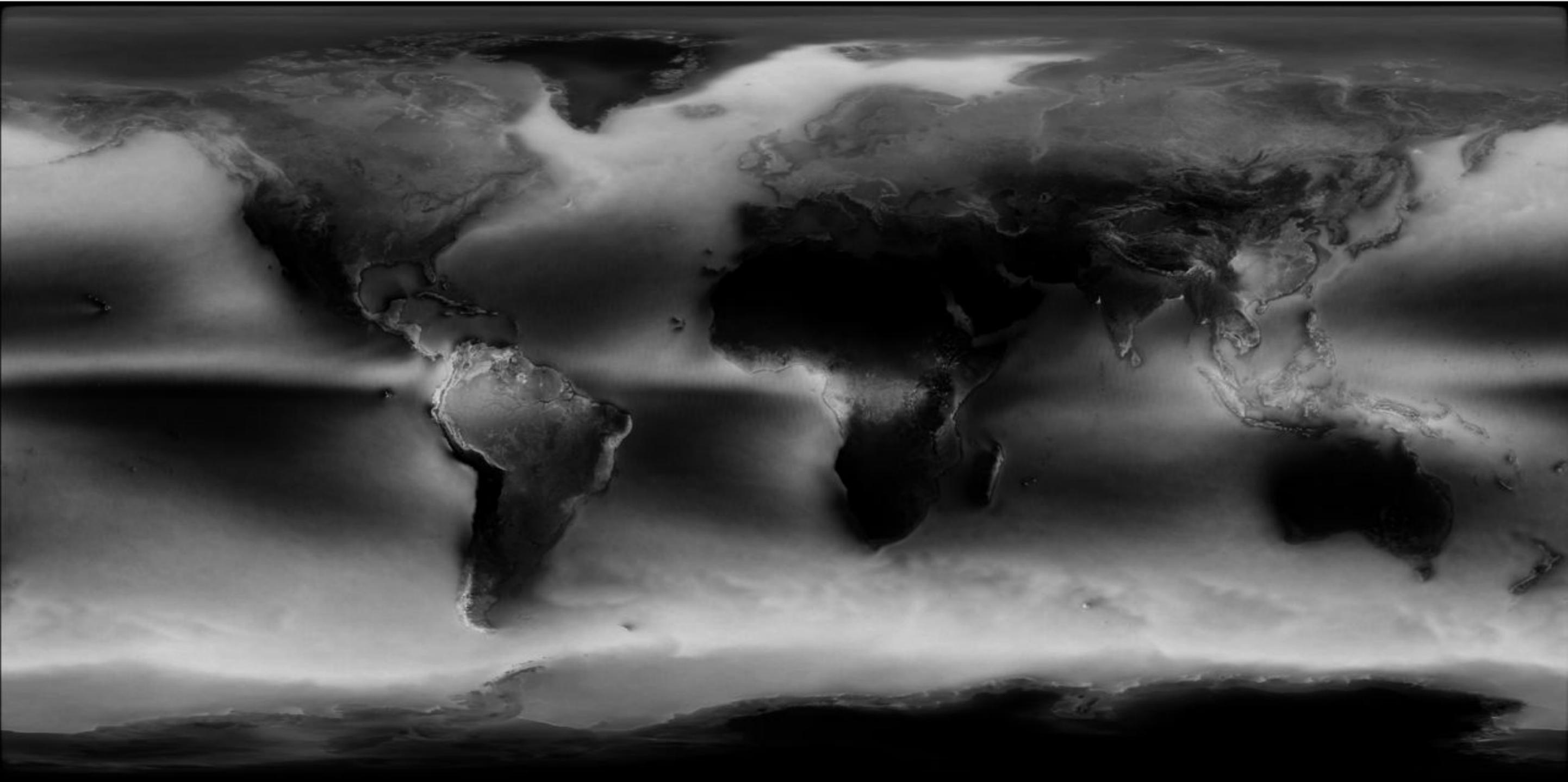
Features ~ geographically fixed, with seasonal variations in intensity

Mean annual *cirrus*-contaminated pixels (another MODIS product)



No detailed spatial structure in cirrus product

Mean annual cloud fraction

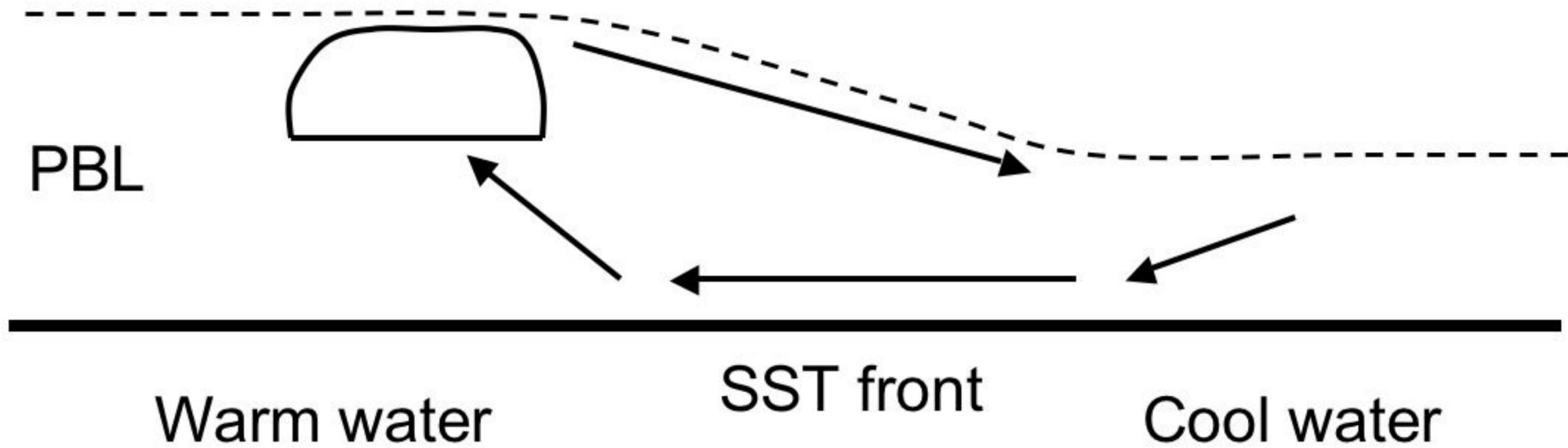


Cloudiness is mostly warm... near surface

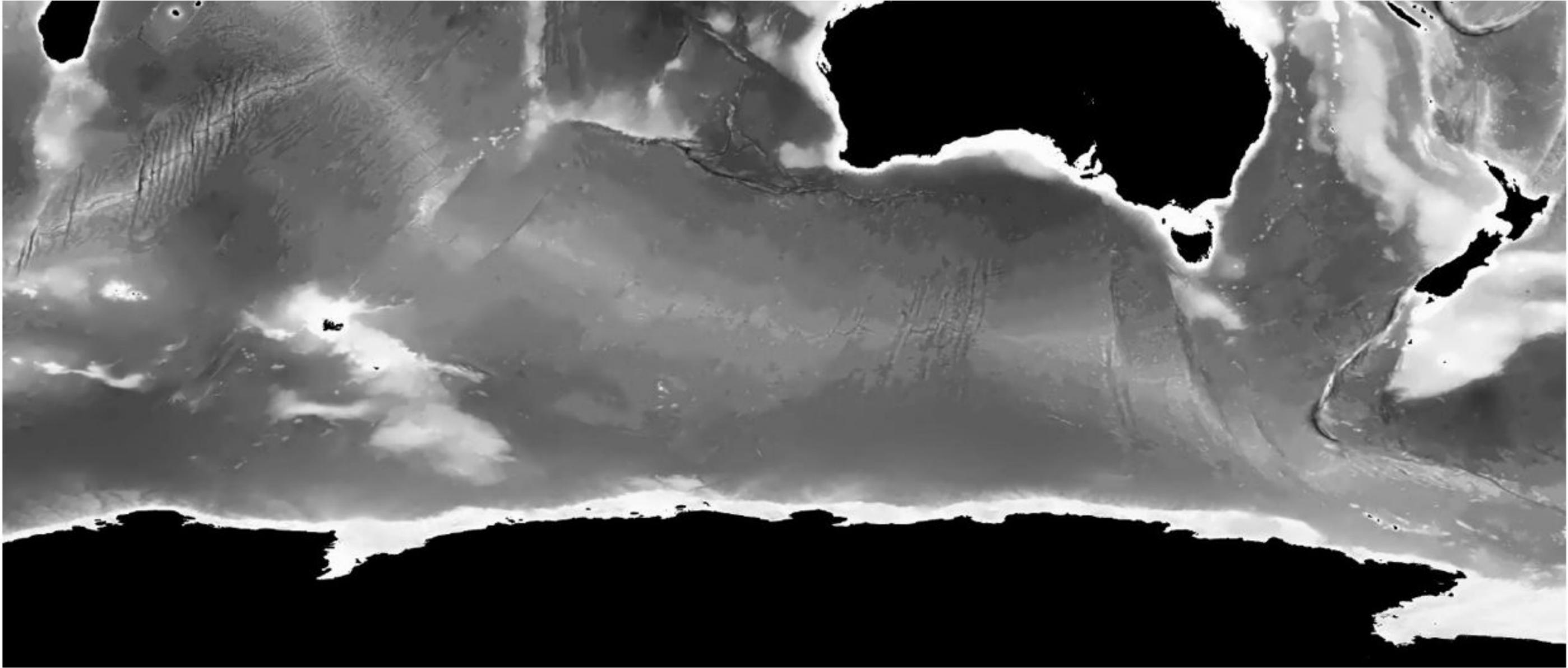
Mean annual SST (from MODIS)



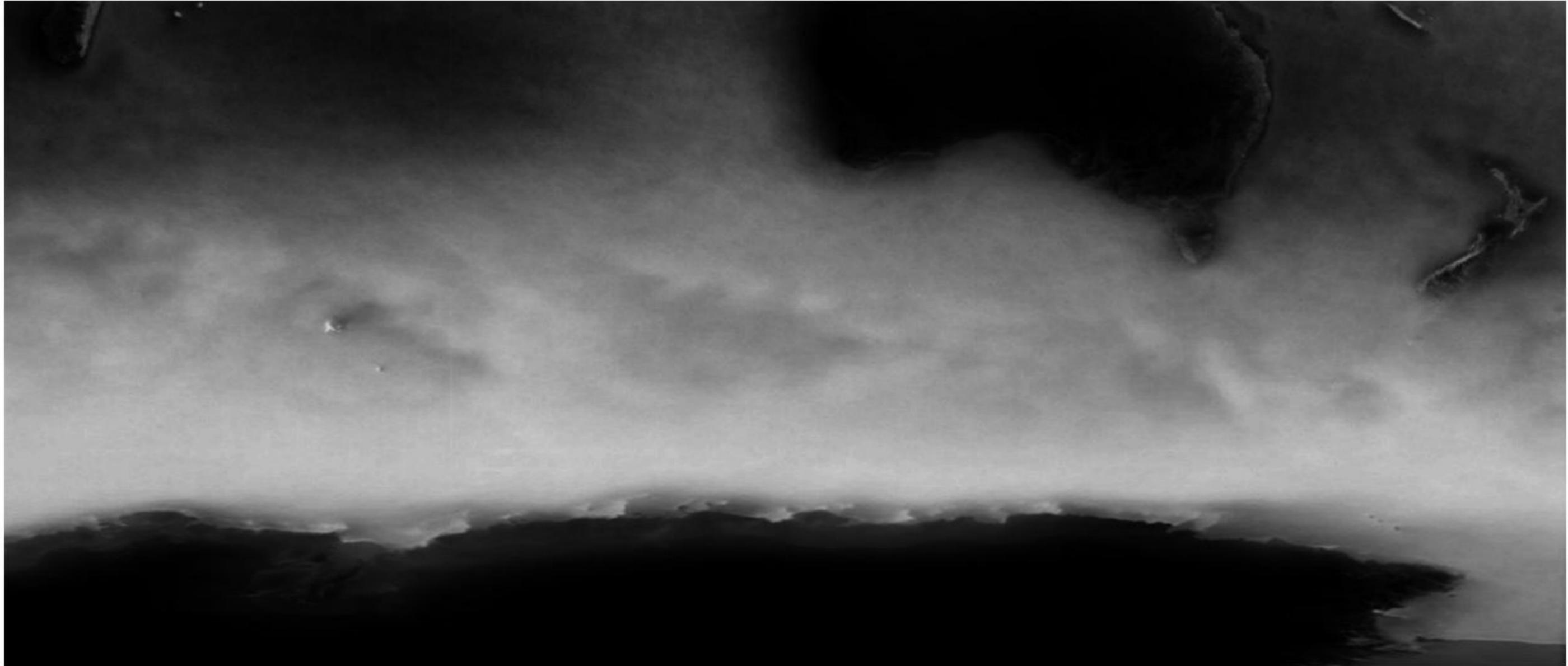
Enhanced clouds on warm side of SST front



bathymetry



Southern summer 11 mean clouds



Southern summer mean SST



Mean annual aqua+terra cloudiness

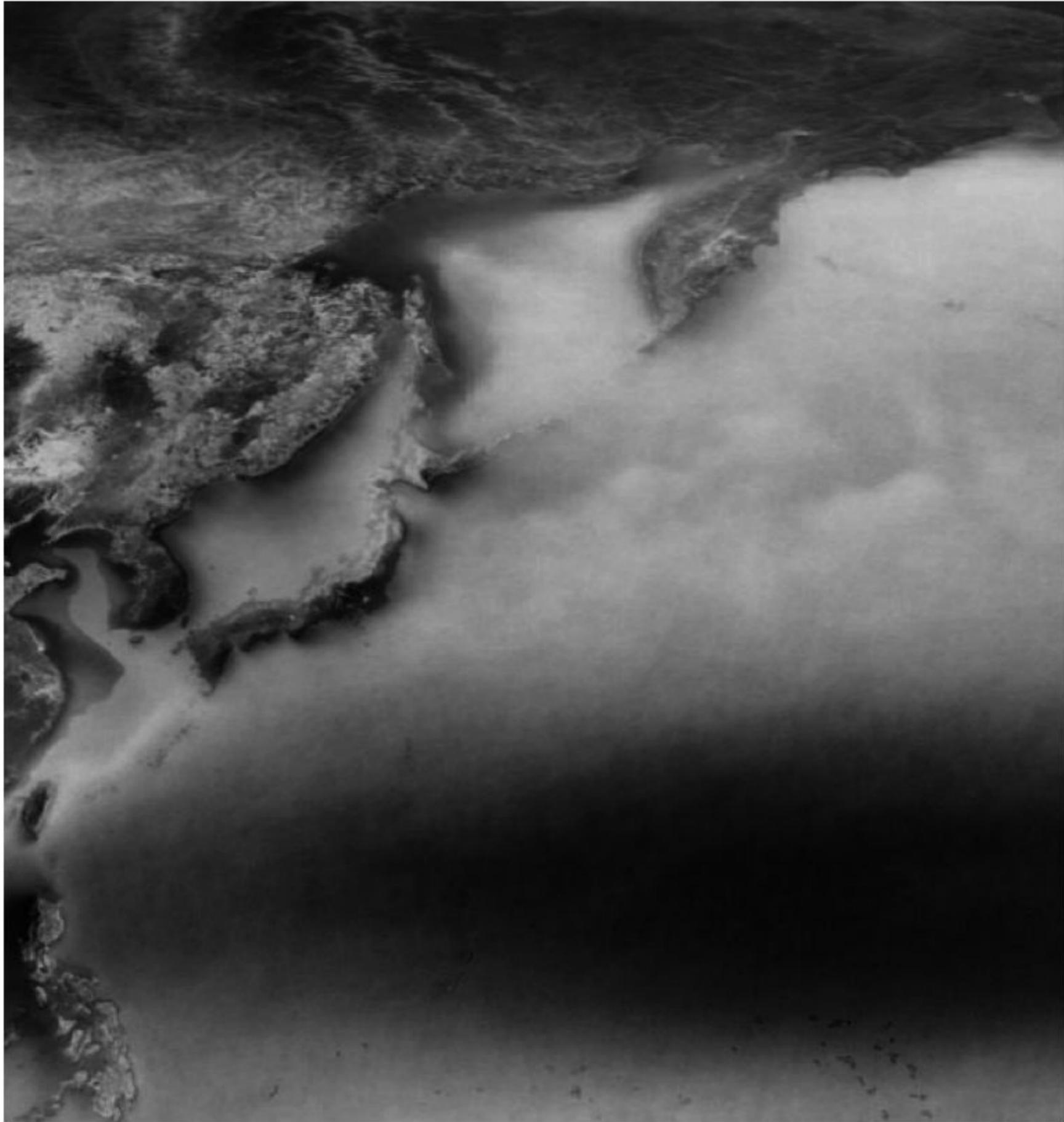


Annual mean SST

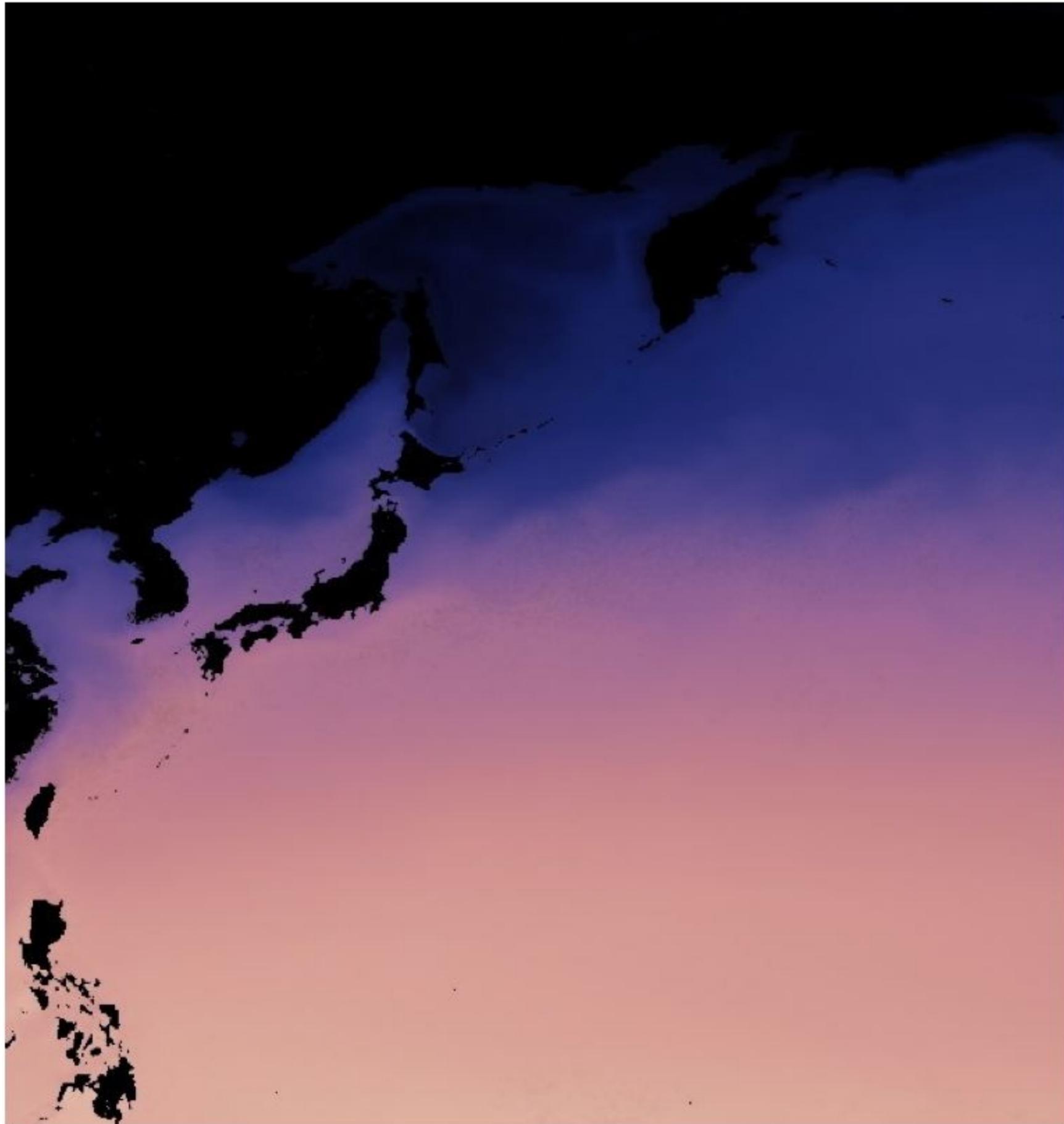


bathymetry

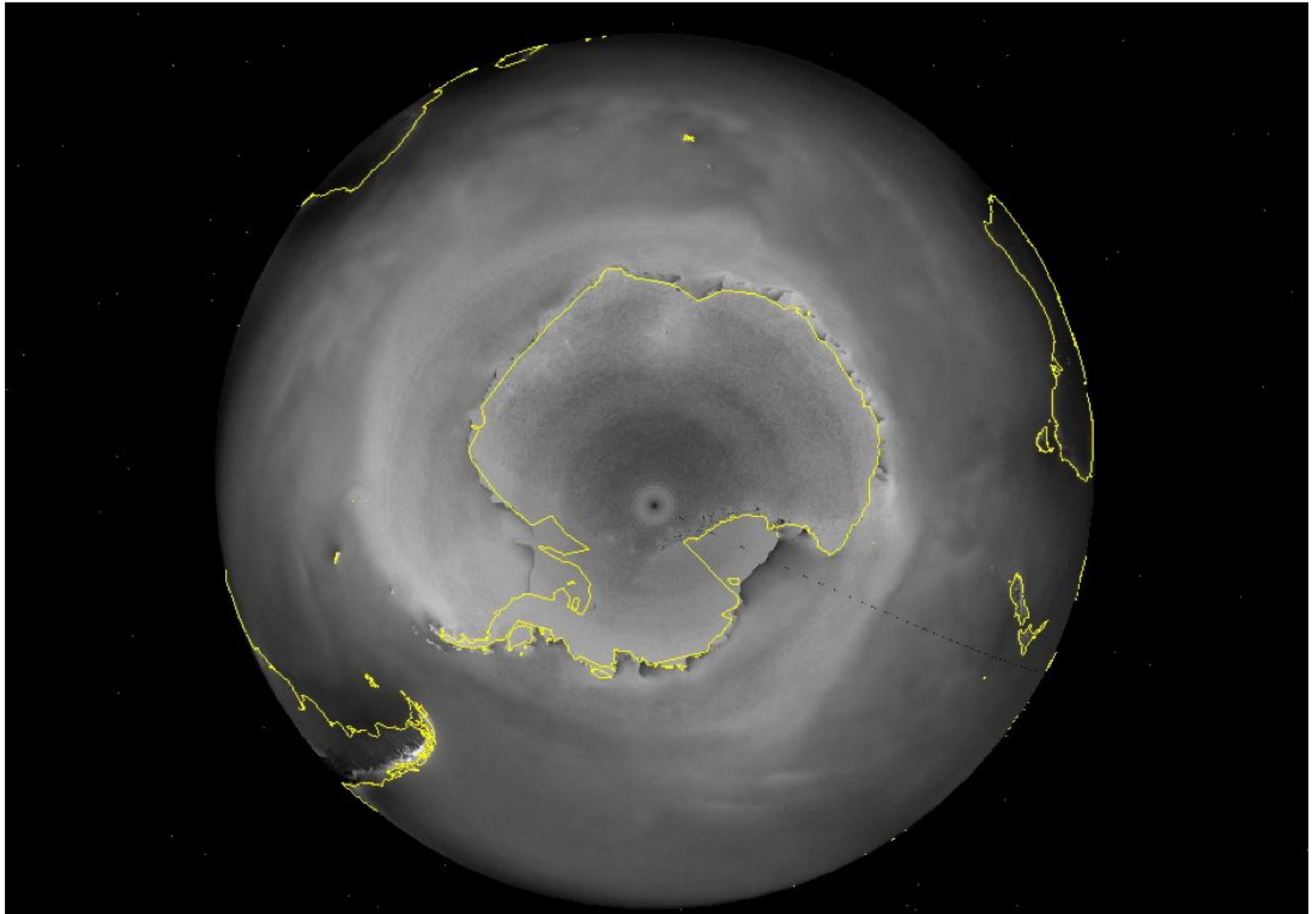




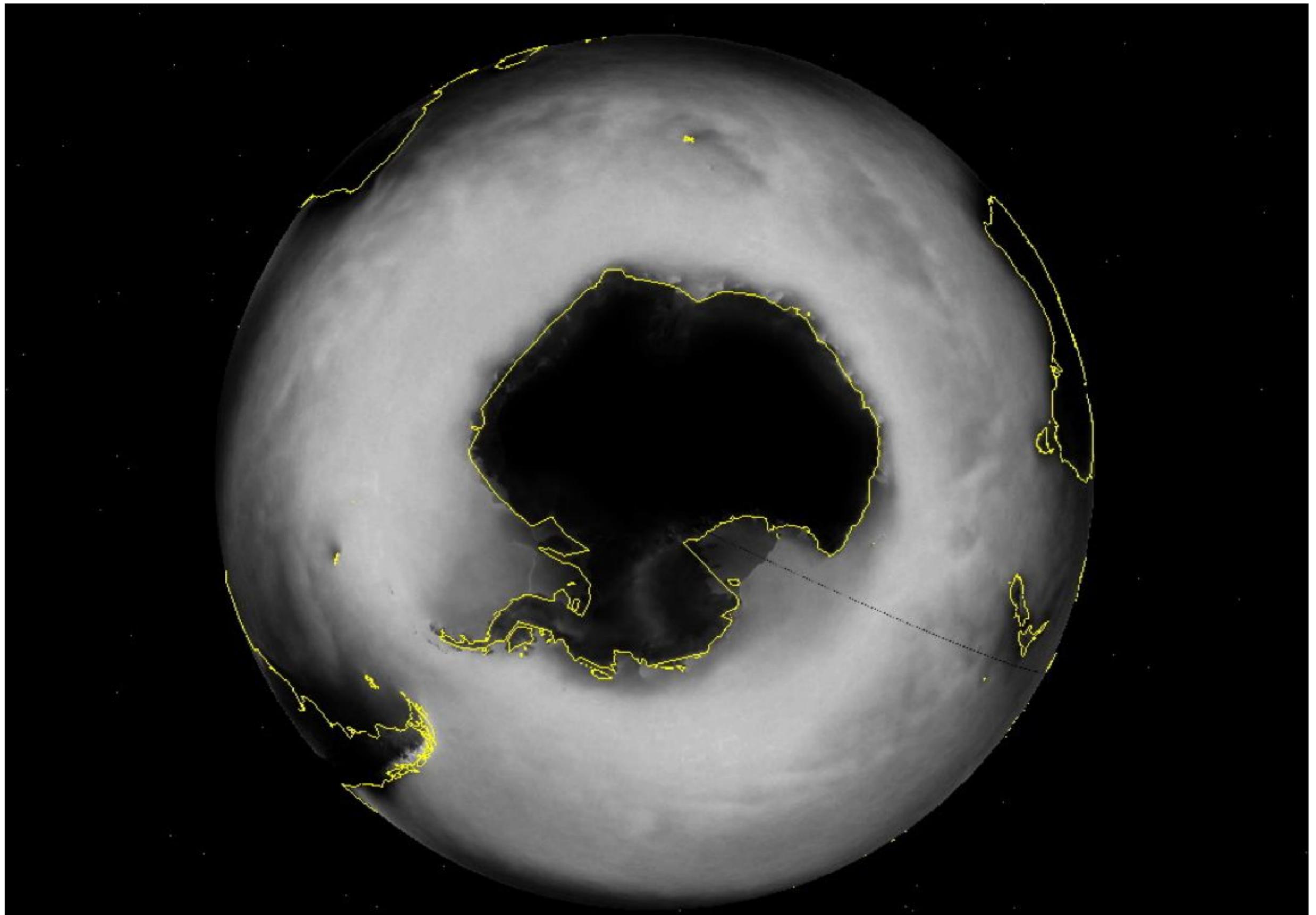
Kuroshio
Winter
clouds



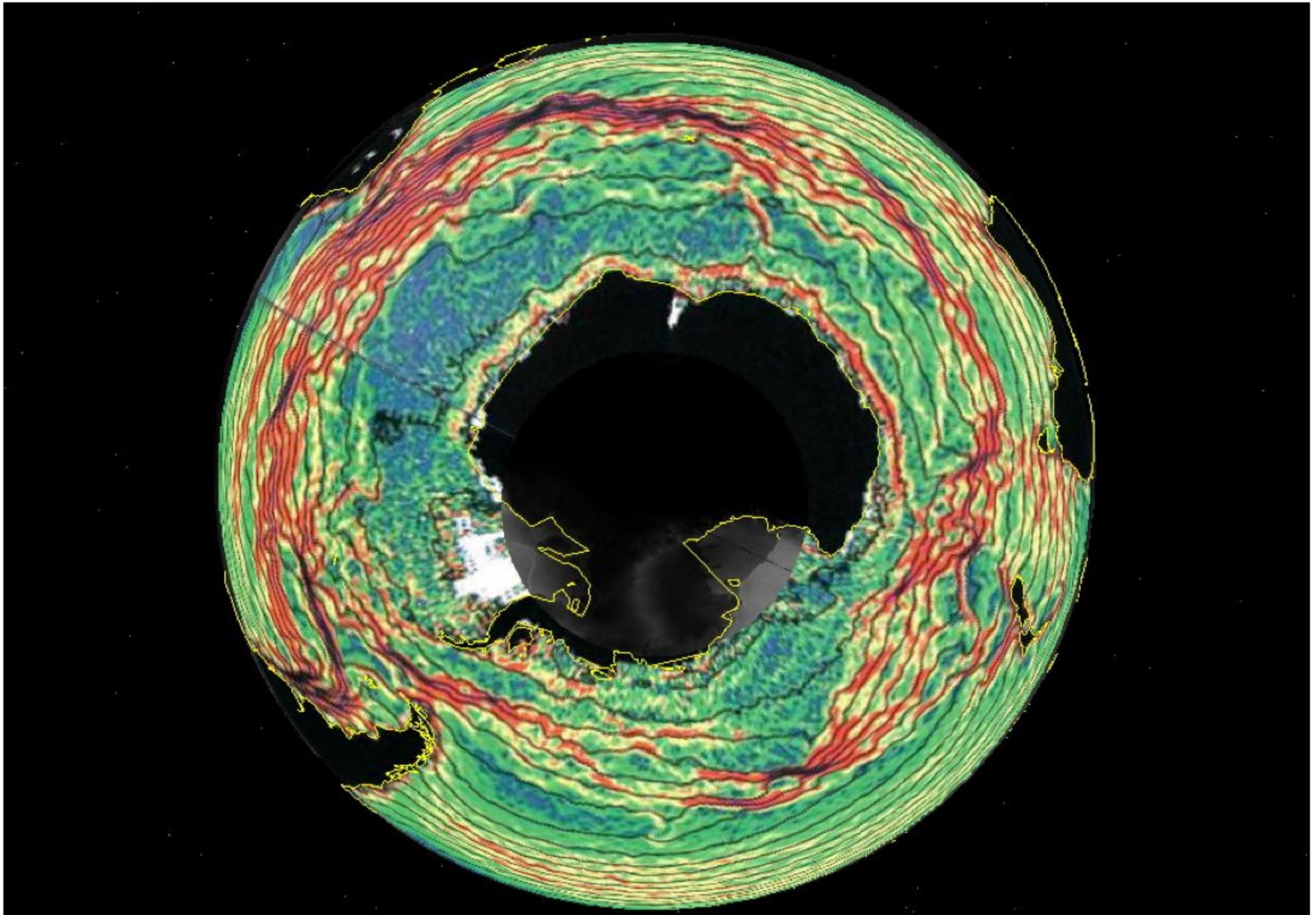
Kuroshio
SST winter
mean



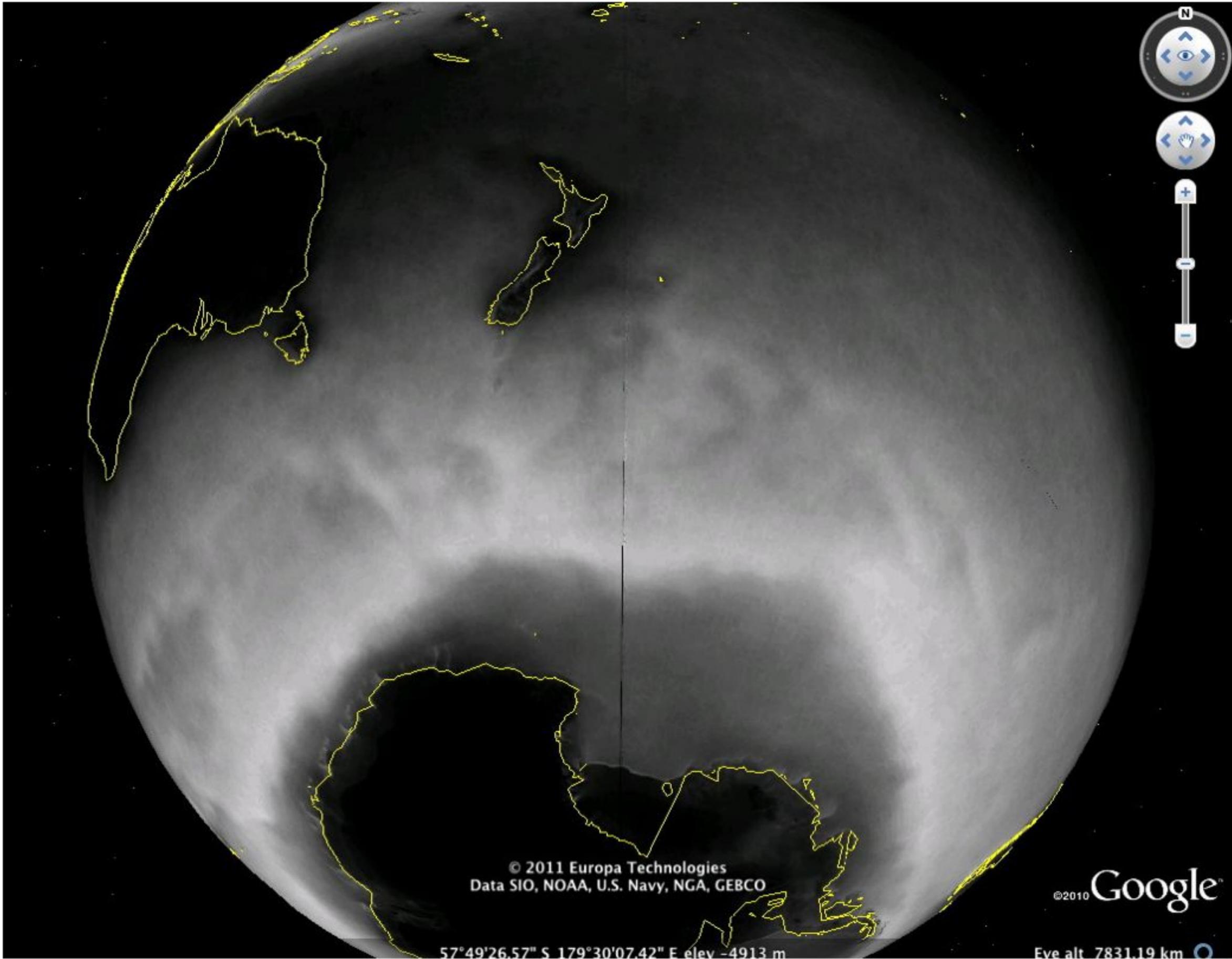
View of South Polar region



44 month mean SST (isotherms and gradient (color))



From Hughes and Ash, 2001, J. Geophys. Res.

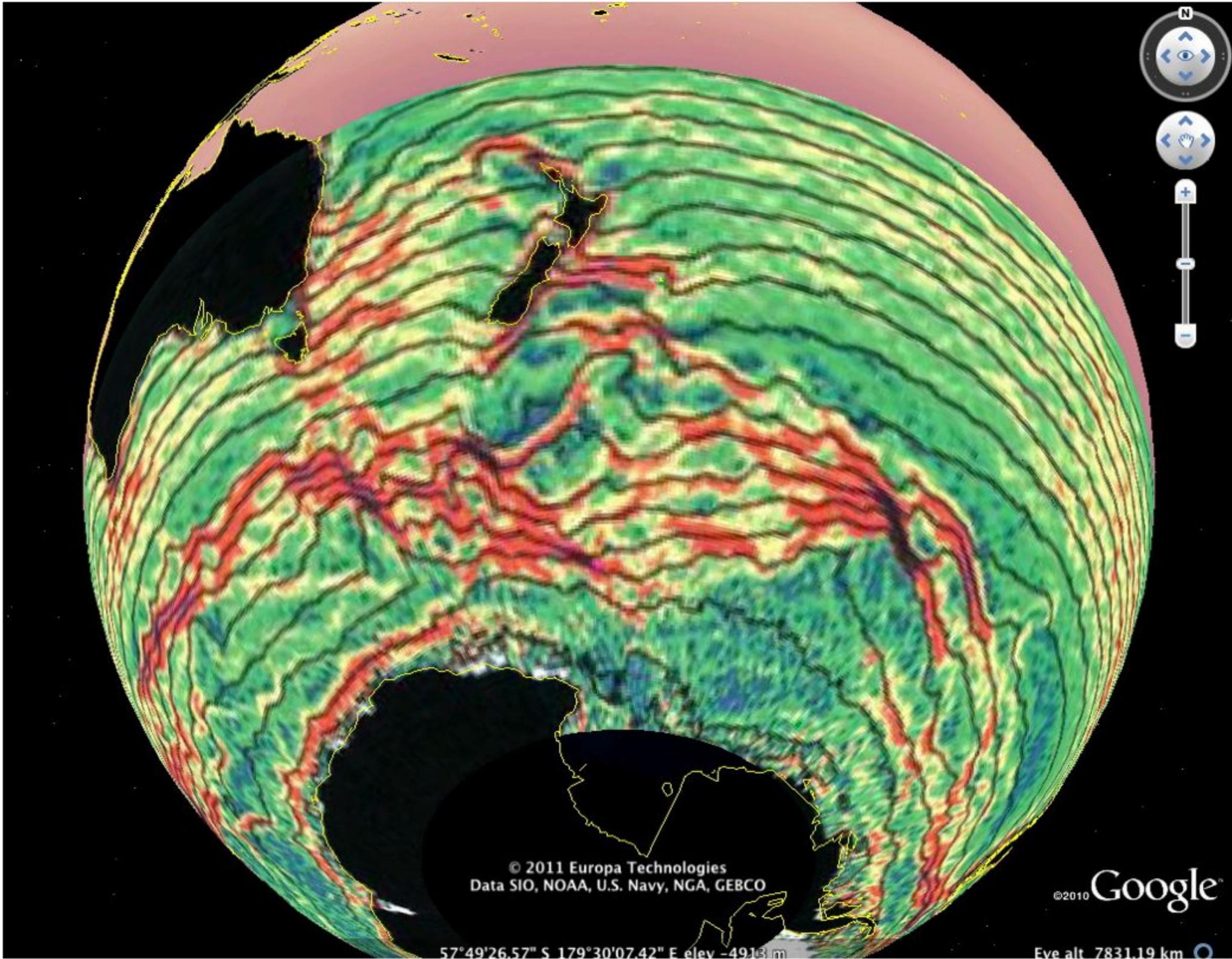


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Data SIO, NOAA, U.S. Navy, NGA, GEBCO

©2010 Google

57°49'26.57" S 179°30'07.42" E elev -4913 m

Eye alt 7831.19 km



Implications and Questions

- Reproducing spatial and intensity details of over-ocean cloudiness implies a coupled ocean-atmosphere model that reproduces accurately the subsurface currents in the deep ocean.
- Time scale for variations of surface SST patterns may be similar to deep ocean circulation time scales. Would the intensity of these cloudiness patterns be useful in monitoring the meridional overturning circulation in the ocean?
- Not clear if these details are important or not; is mean cloudiness over Southern Oceans the same if meridional SST gradient were uniform?

Summary

- MODIS ~decade long record of visible imagery shows cloudiness patterns tied to SST gradients in extratropics (especially Southern Hemisphere) which are tied to details of bathymetry.
- Quick-look data can be very valuable if made available in easily accessible formats (perhaps this cloud SST relationship could have been identified years ago(?))
- www.nssl.noaa.gov/projects/pacs/ for access to imagery...

(SHOW LOOPS)