Global Near Real-Time MODIS-based Flood Mapping: Upcoming Improvements and Transition to LANCE

NDRC Webinar

1 April 2020

Dan Slayback

Science Systems & Applications, Inc

Biospheric Sciences Laboratory

NASA Goddard Space Flight Center

dan.slayback@nasa.gov

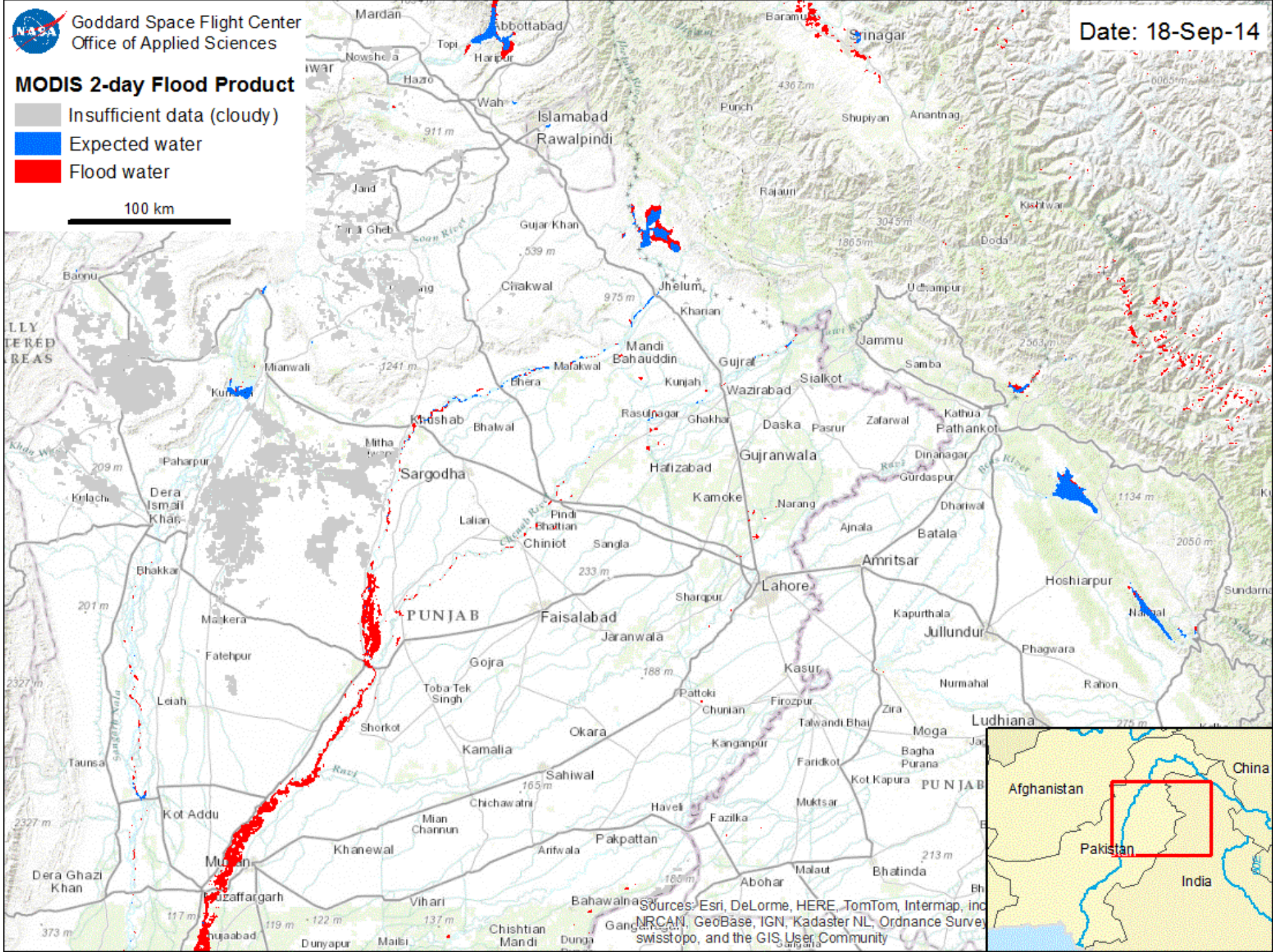
PI: Fritz Policelli, NASA GSFC Hydrology Lab

Co-Is: Bob Brakenridge, Albert Kettner: Dartmouth Flood Observatory, University of Colorado

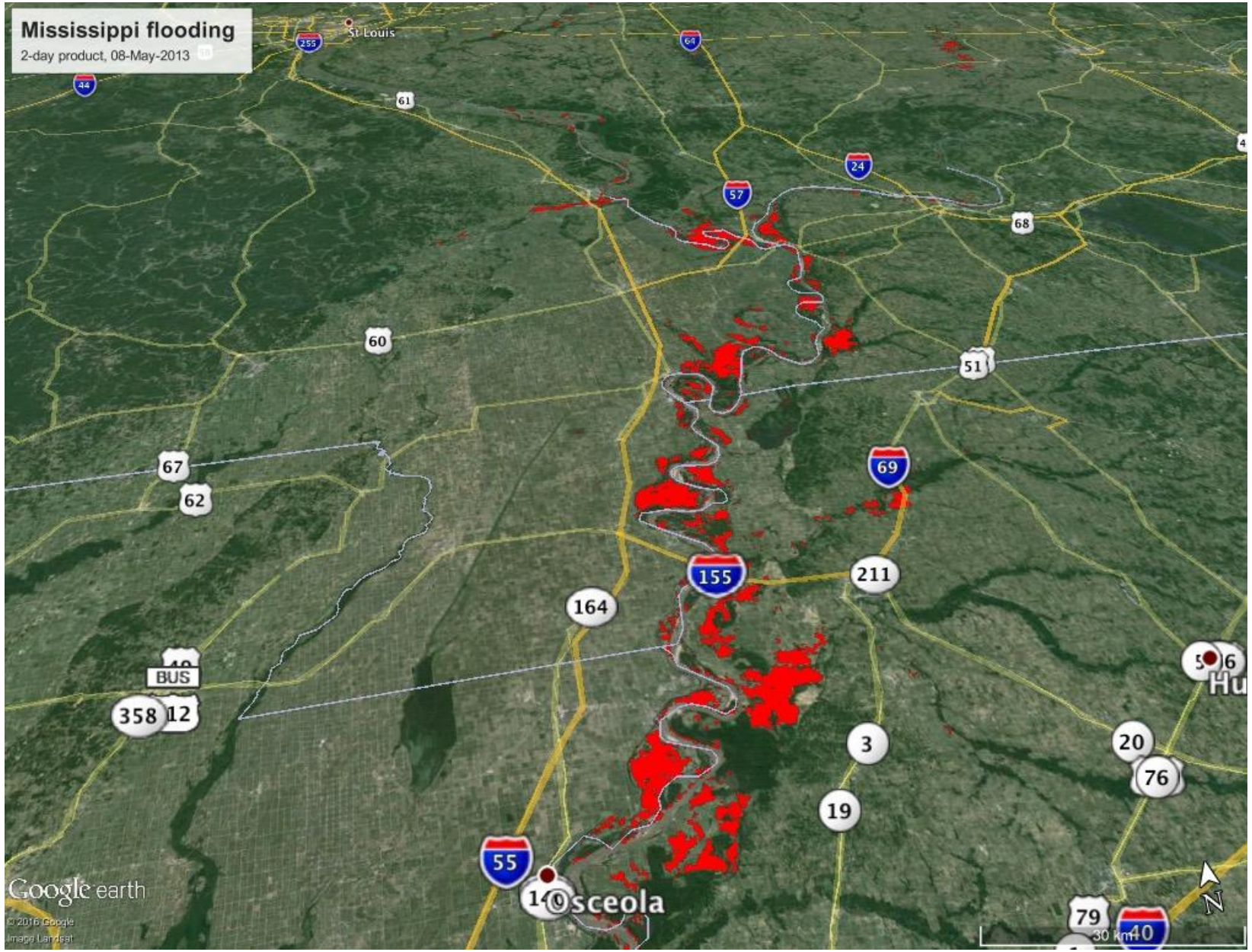
Goddard Space Flight Center

SE Asia flooding – Oct 2011

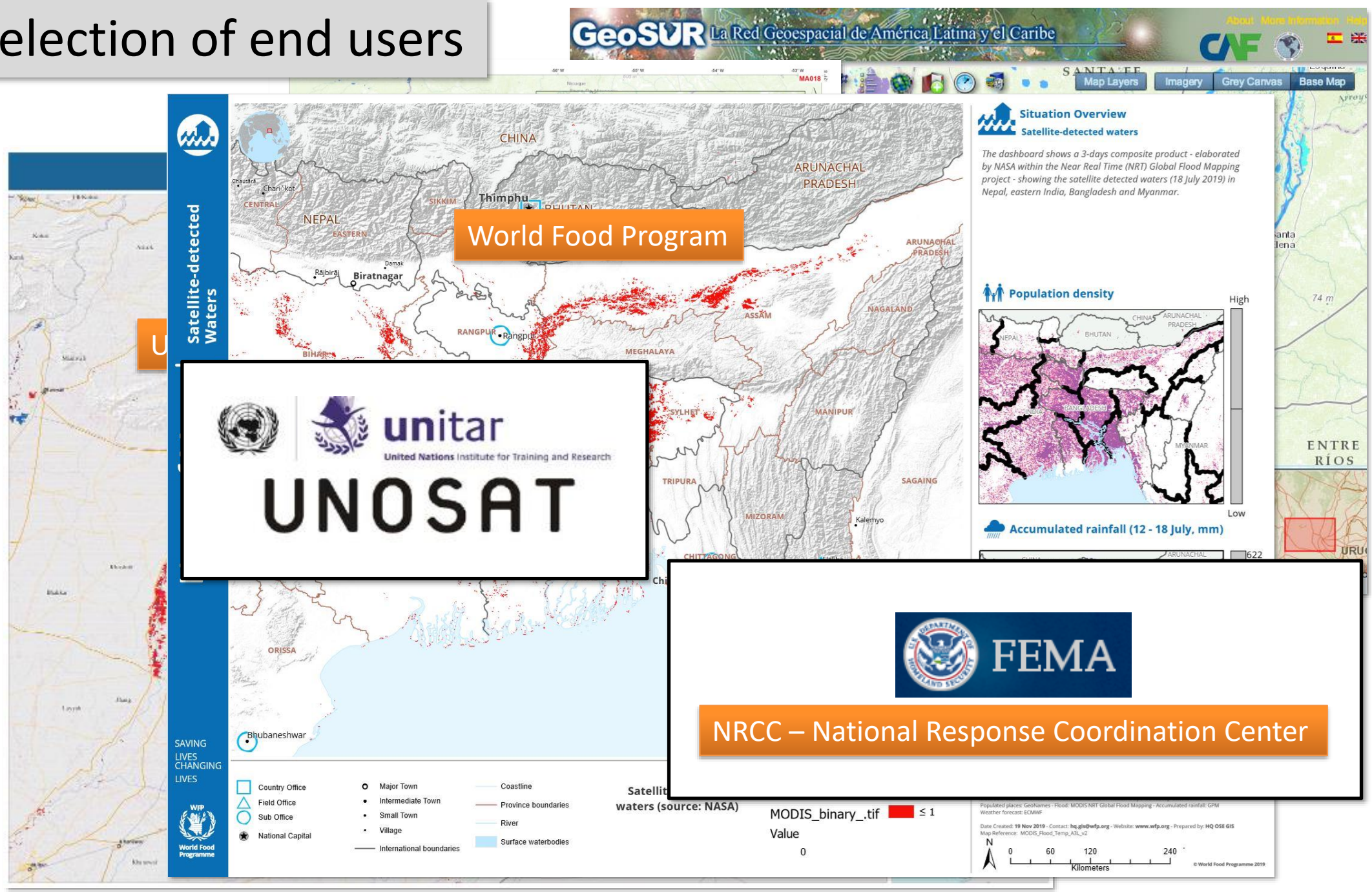
Indus Flooding Sept 2014



Mississippi river flooding – May 2013

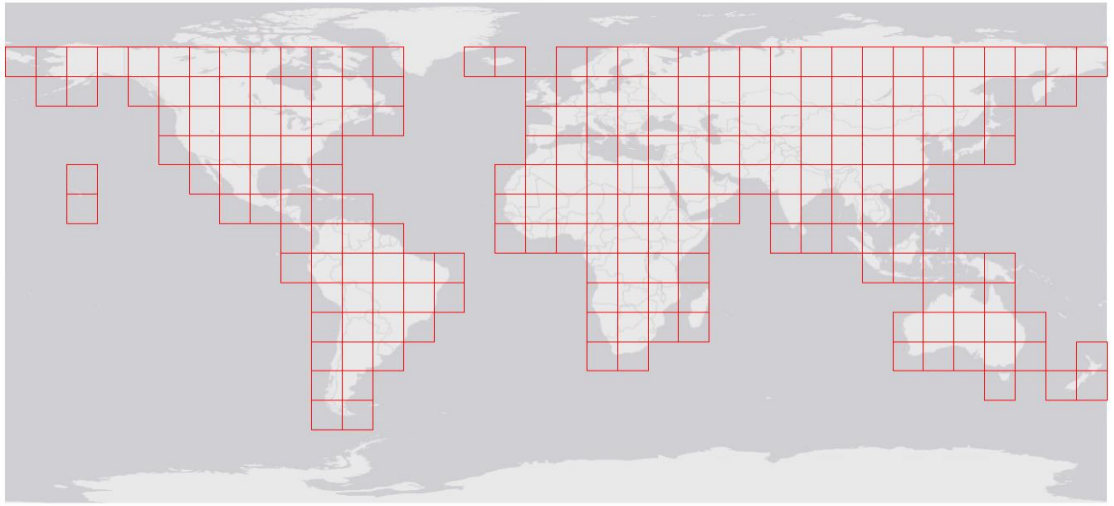


Selection of end users



A brief history

- Early 2000s: Bob Brakenridge (Dartmouth Flood Observatory): manual generation of flood maps using MODIS rapid response imagery as source
- Generally effective, but:
  - Not automated!
  - Used rapid response jpegs not intended for data analysis
- ~ 2010, NASA GSFC's Office of Applied Science initiated a project to automate production
  - Using LANCE-generated NRT surface reflectance
  - Automated global flood map production began 2012:
    - 223 10x10° tiles x 3 products (2-day, 3-day, 14-day) = 669 daily product suites generated.
    - Typically available within 6 hours of Aqua overpass (~ 8:00 PM local time).
  - Now transitioning full production into LANCE

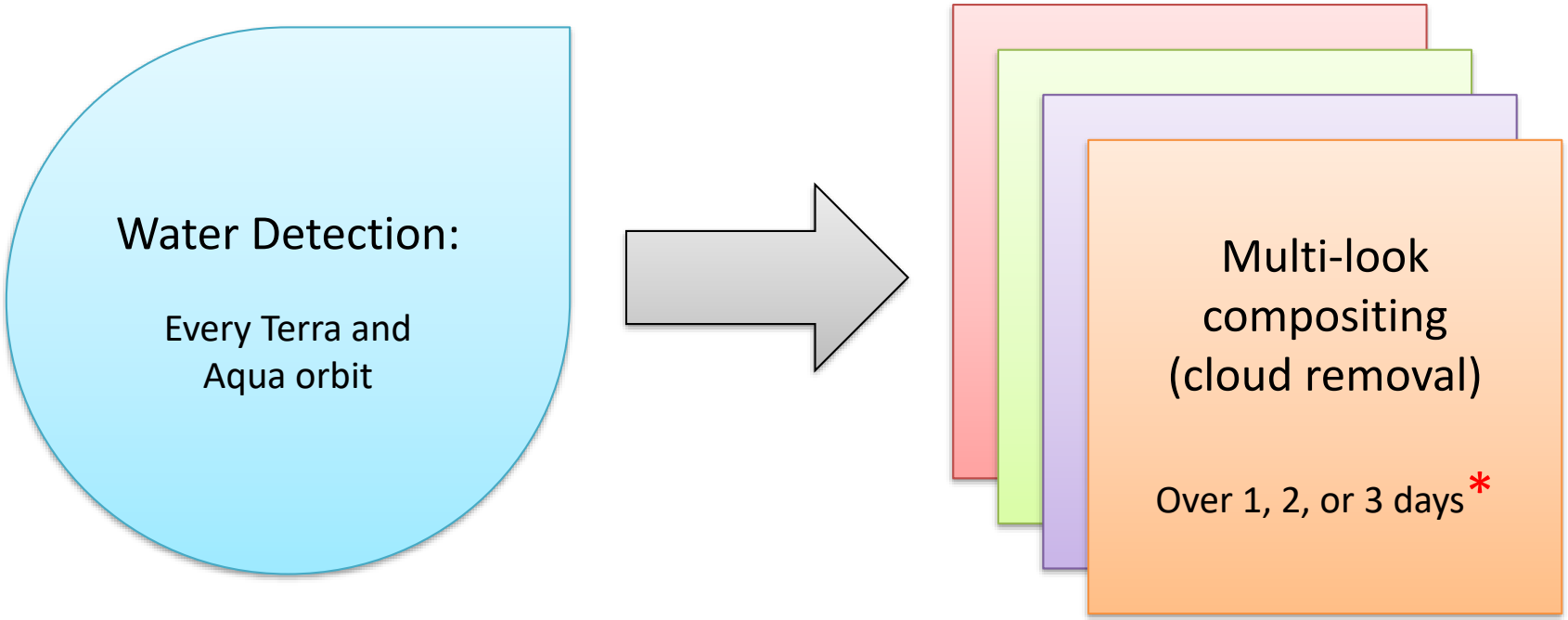


Current Status

- LANCE transition nearly complete….mid 2020?
  - Has required a complete rewrite of code running on PI-owned server: from a combination of IDL/ENVI, python, and perl, to perl and PDL (Perl Data Language).
  - Code architecture updated and simplified, but requires some new approaches to production rules in LANCE/MODAPS for the multi-day compositing.

- Other benefits to LANCE transition
  - Reduced latency of product generation; can process as soon as incoming granules are available. (previously scheduled at ~8pm local time).
  - Add needed improvements: updated reference water, “recurring flood”, improved masking
  - Product browseable within ESDIS/Worldview interface – much more powerful end-user experience
  - Possible back-processing of MODIS archive, providing ~20 year history of earth surface water dynamics at 250m resolution

Approach: two key steps



* Depends on cloud cover at site of interest

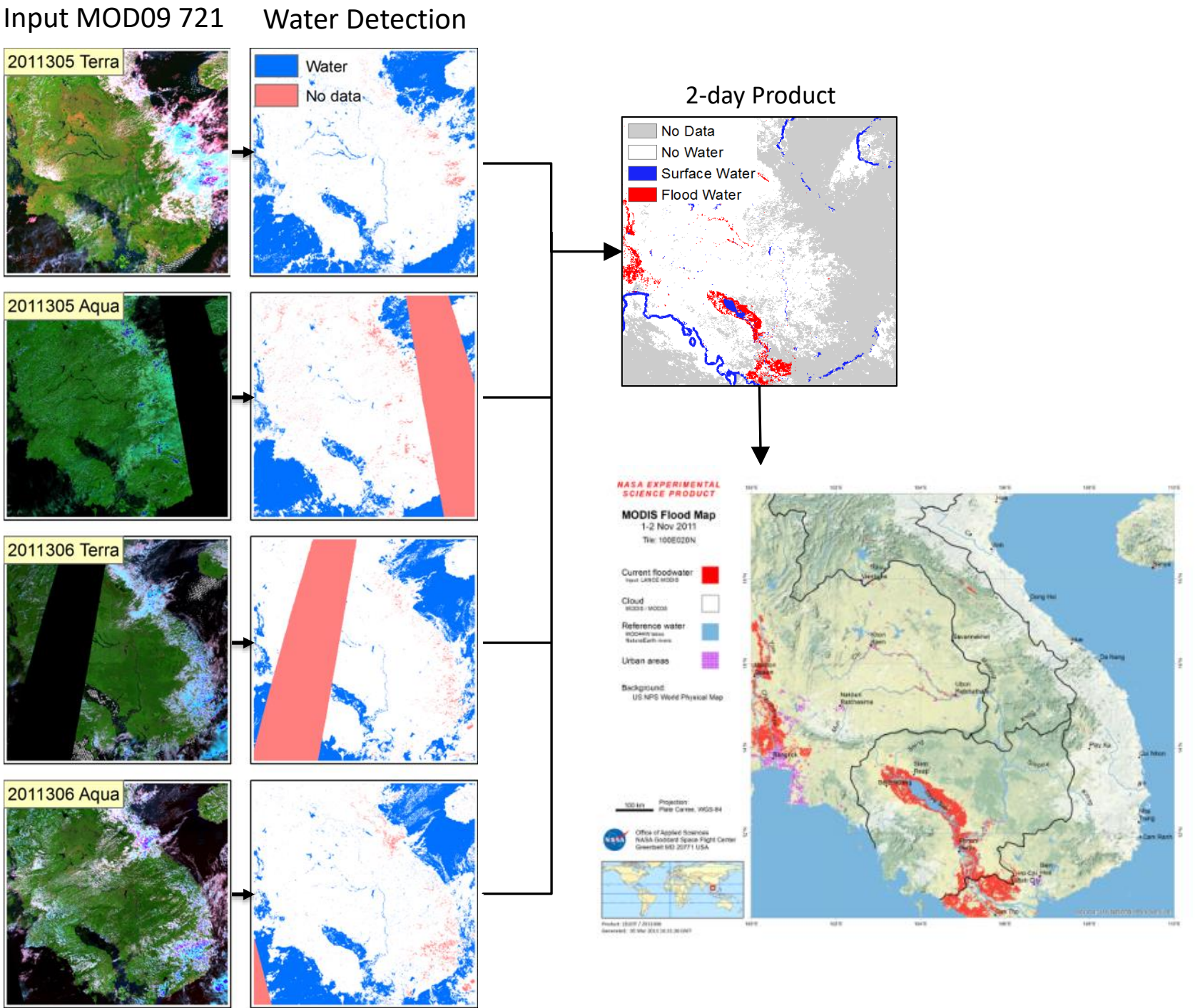
Approach: in more detail

1. Water Detection
   - Apply algorithm to all incoming MOD09 (surface reflectance) swath data granules
2. Multi-look compositing
   - Require multiple water observations to mark a pixel as water (generally)
3. False-positive masking
   - Remove likely cloud-shadow and terrain-shadow false positives
4. Determination of flood
   - Compare detected water to reference of permanent water (lakes, rivers), and to recurring flood areas, to provide a product showing:
     1. Surface water (= expected water)
     2. ***NEW in LANCE*** Recurring flood (= flood occurring in areas where frequently previously detected)
     3. Flood (= flood occurring in areas where not frequently previously detected)
     4. Insufficient data (clouds, NODATA, etc) (= potential false negatives)

Multi-look compositing example

SE Asia Floods 2011

Tile: 100E020N
Dates: 1-2 Nov 2011
Composite: 2D2O = 2-day 2-obs.



1. Water Detection: Input data

LANCE NRT MODIS Surface Reflectance product (MOD09):

- Daily Terra and Aqua SR bands 1, 2 (250 m) and band 7 (sharpened to 250 m)
  - Used in core water detection algorithm.
- Cloud mask flag (from MOD09 QA State Layer)
  - Informs when we cannot see the surface; NODATA (really: no SURFACE data)
  - Pre-LANCE: used MOD35 cloud product
- Cloud shadow flag (from MOD09 QA State layer)
  - Assists with removal of cloud-shadow false-positives.
  - Pre-LANCE: used MOD06 / Atmosphere and geometrically projected clouds from MOD35

2. Multi-look compositing

- 2-day **standard product** (2D2O): Requires 2 water observations over 2 days (potentially 4 observations).
- 3-day product (3D3O): Requires 3 water obs over 3 days. Minimal false-positives. Potentially less current.
- 1-day product (1D1O): Requires JUST 1 observation over 1 day.
  - Most current, but **WILL** contain cloud-shadow false-positives **IF** cloud is present.

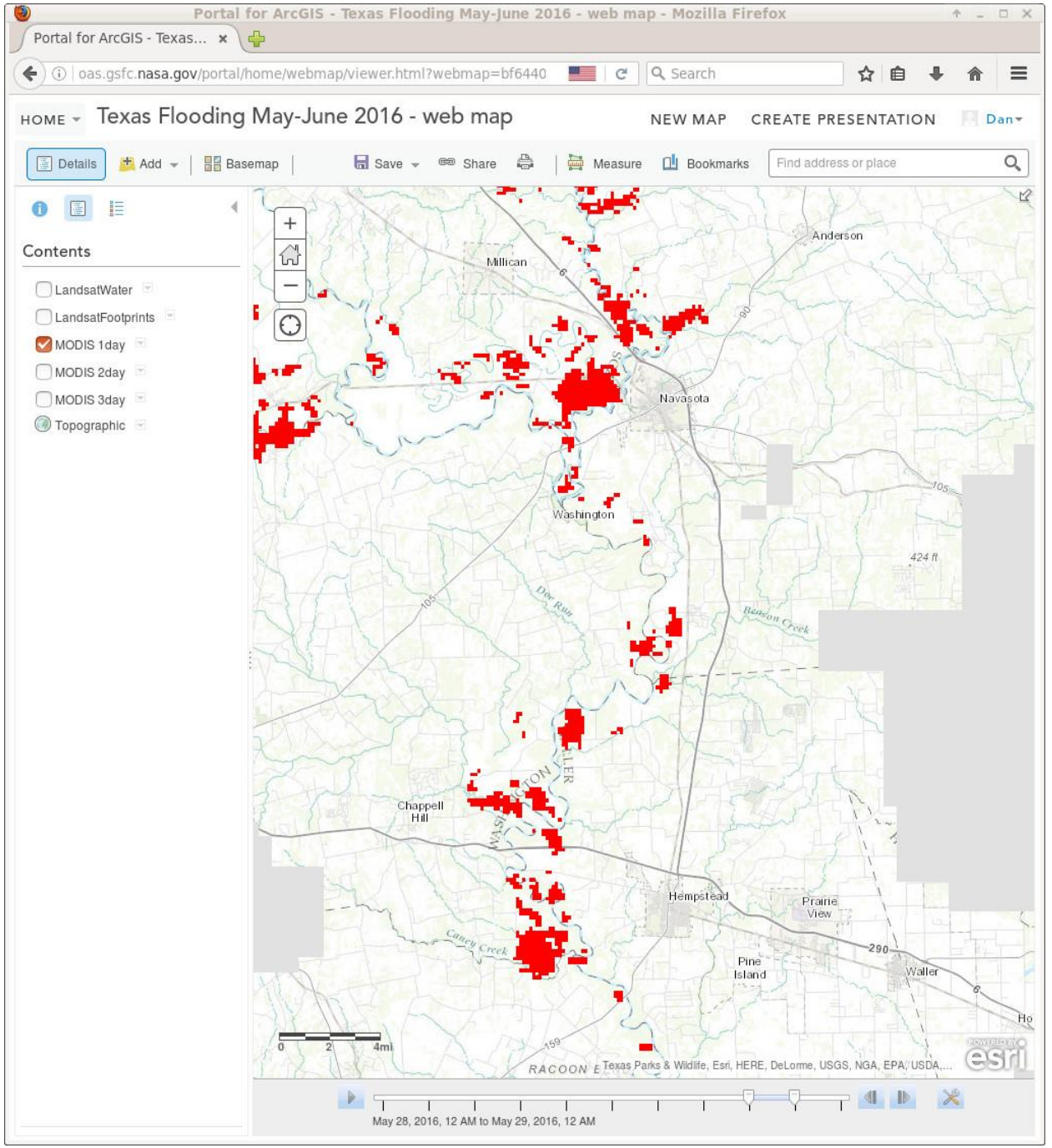
- Which to use? It depends on cloud conditions, and:
  - Tolerance for false positives (and false negatives).
  - Need for only the most up-to-date information.

- Clear conditions? (Can verify visually in Worldview app: https://worldview.earthdata.nasa.gov/) Use 1-day.
- Very sensitive to false-positives and/or currency is not critical? Use 3-day.
- Need the latest info? Use 1-day, but you MUST check cloud cover!
- Best approach? Review all products, check cloud cover, and evaluate for given event and needs.

Impact of composite period:

1-day product

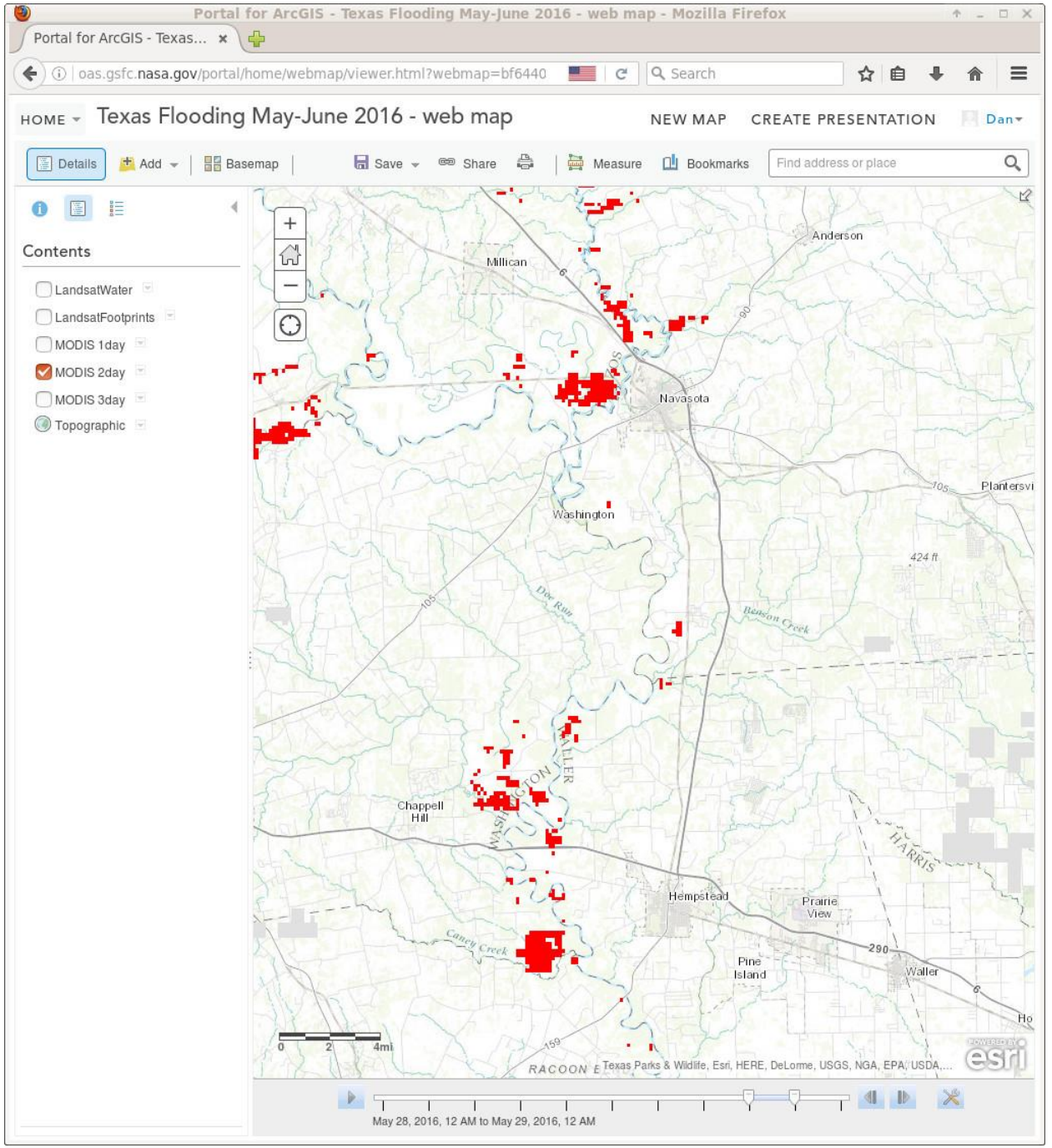
Houston-area flooding June 2016



Impact of composite period:

2-day product

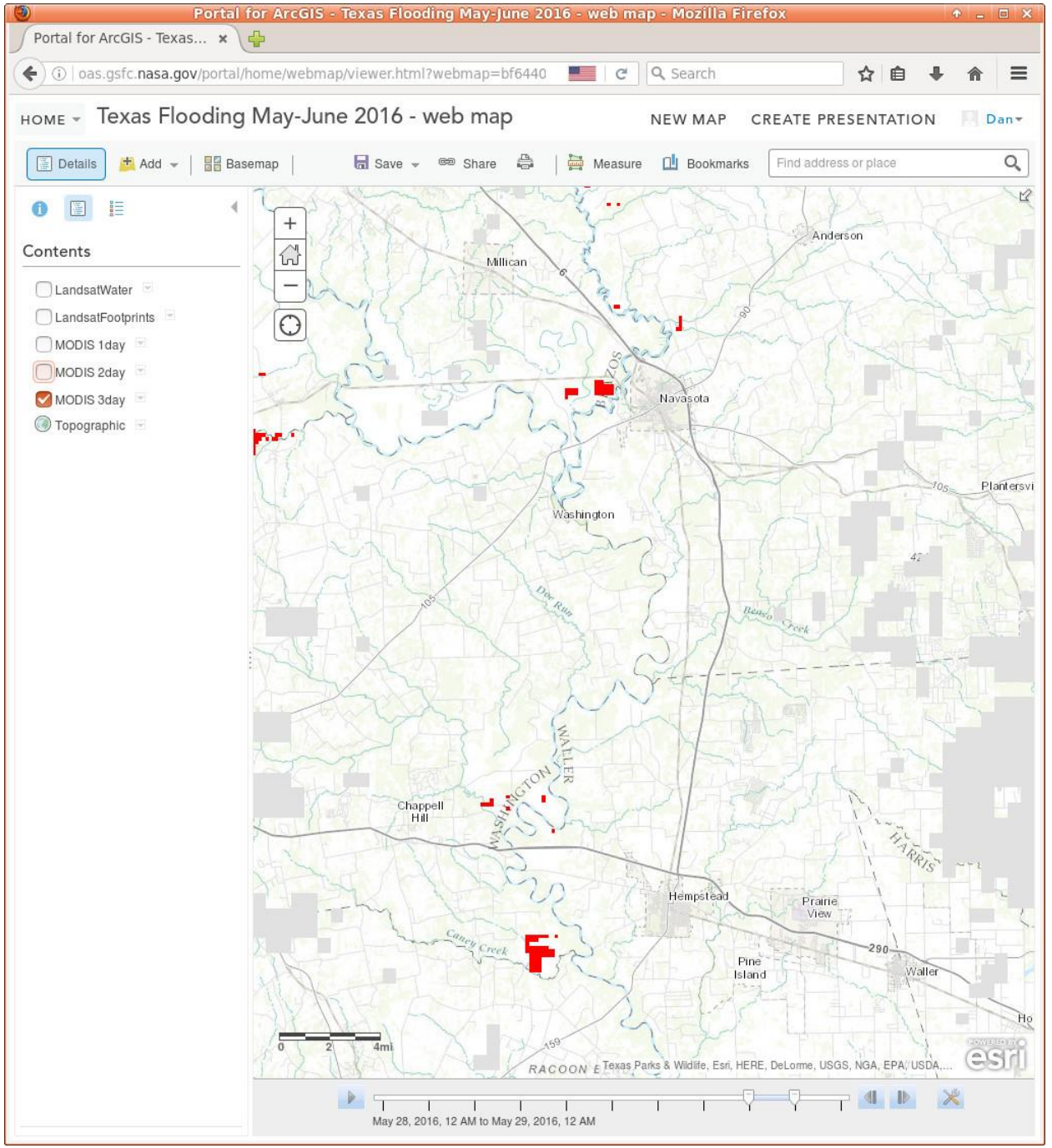
Less flood shown → cloud preventing multiple water observations



Impact of composite period:

3-day product

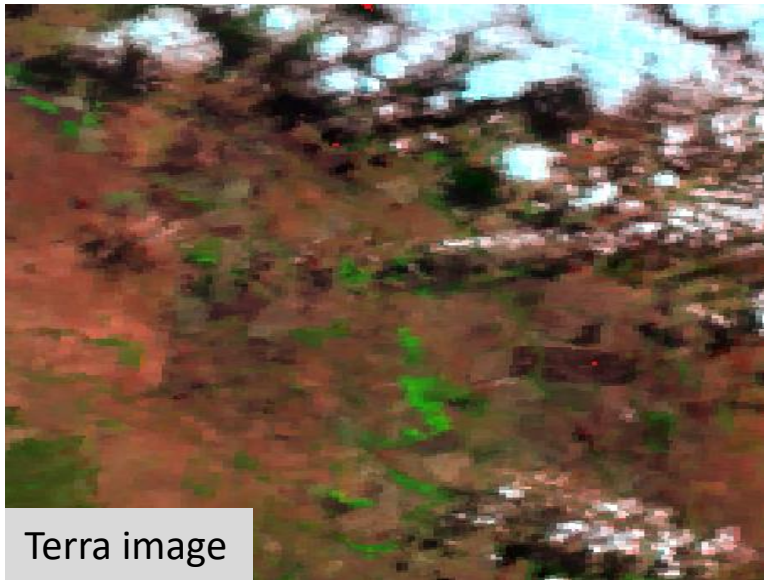
Even less flood shown → not helpful



Impact of composite period

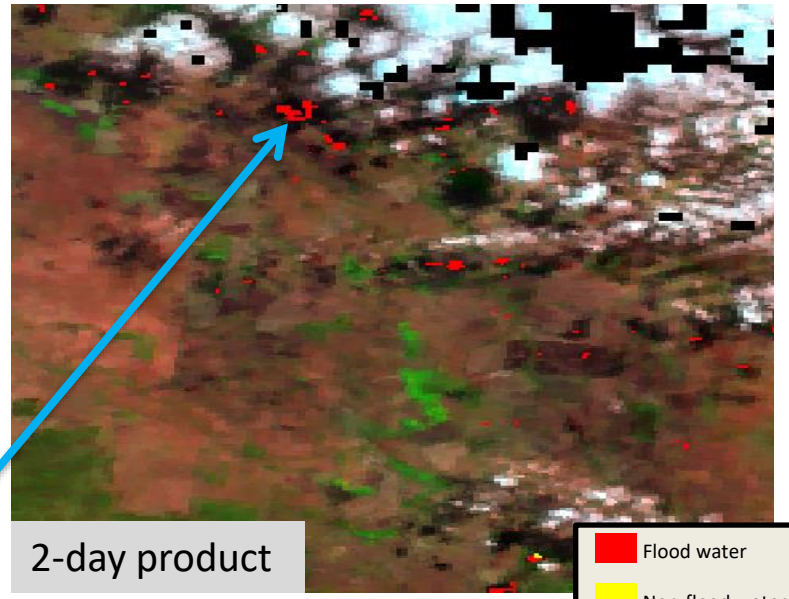
Cloud-shadow removal: 2 vs 3-day product

→ 3-day is better



Terra image

3-day product removes cloud shadow false-positives persisting in 2-day product



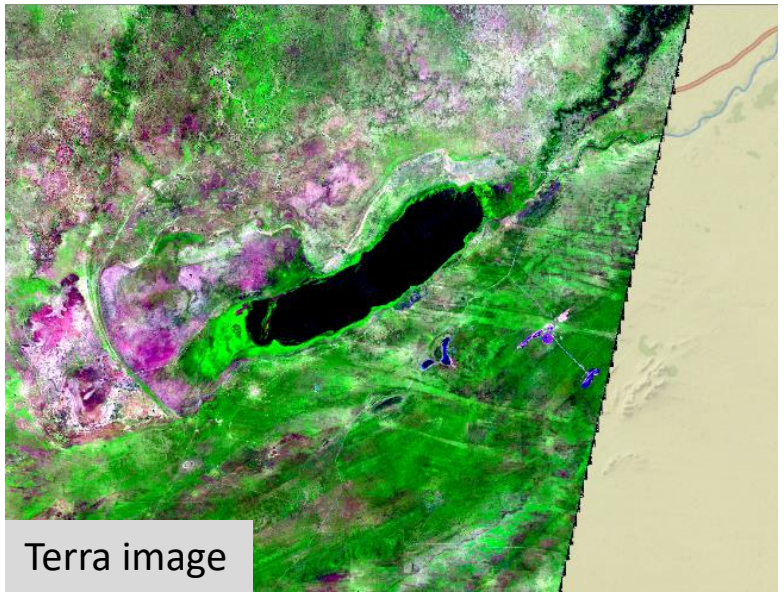
2-day product

3-day product

Impact of composite period

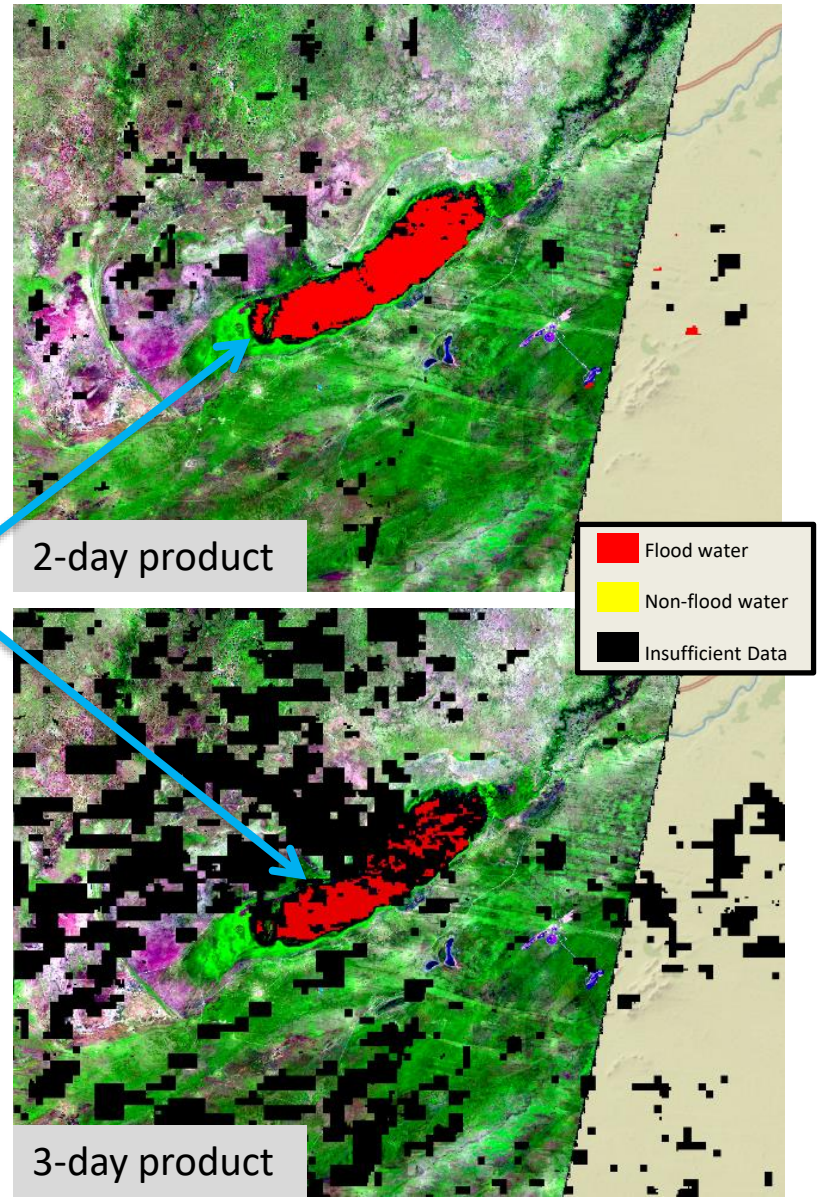
Cloud-shadow removal: 2 vs 3-day product

→ 2-day is better



Terra image

2-day shows better coverage of flood zone;
3-day patchy due to cloudiness

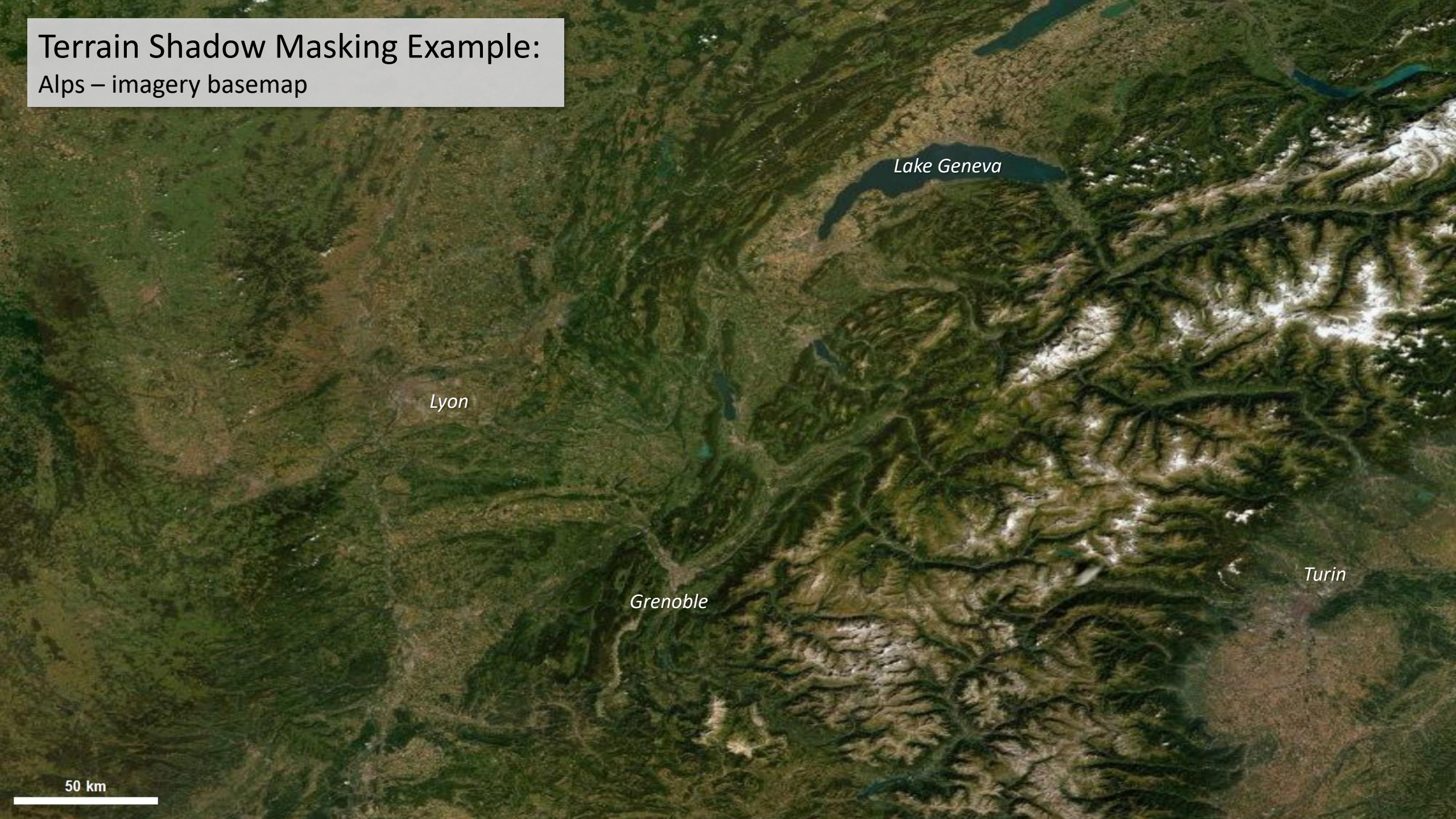


3. False-positive masking

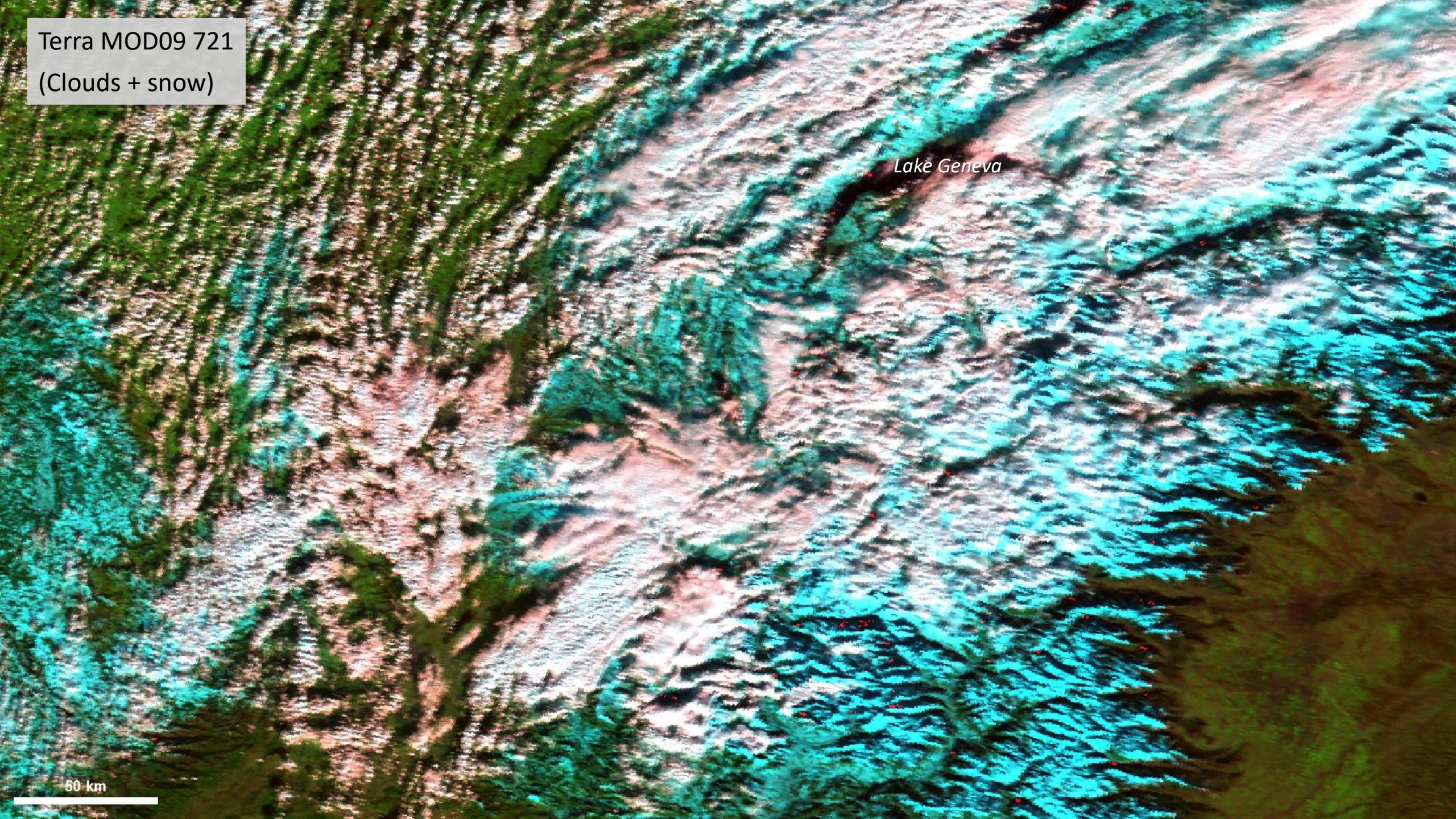
- Shadows look like water!
- Terrain shadows
  - In mountainous areas, mostly in winter
  - To filter, we use pre-computed shadows (good but not perfect)
  - New – apply HAND topographic mask
- Cloud shadows
  - Multi-look compositing mostly eliminates
  - For 1-day, we apply the cloud shadow mask included in MOD09 product
    - Imperfect, but helpful

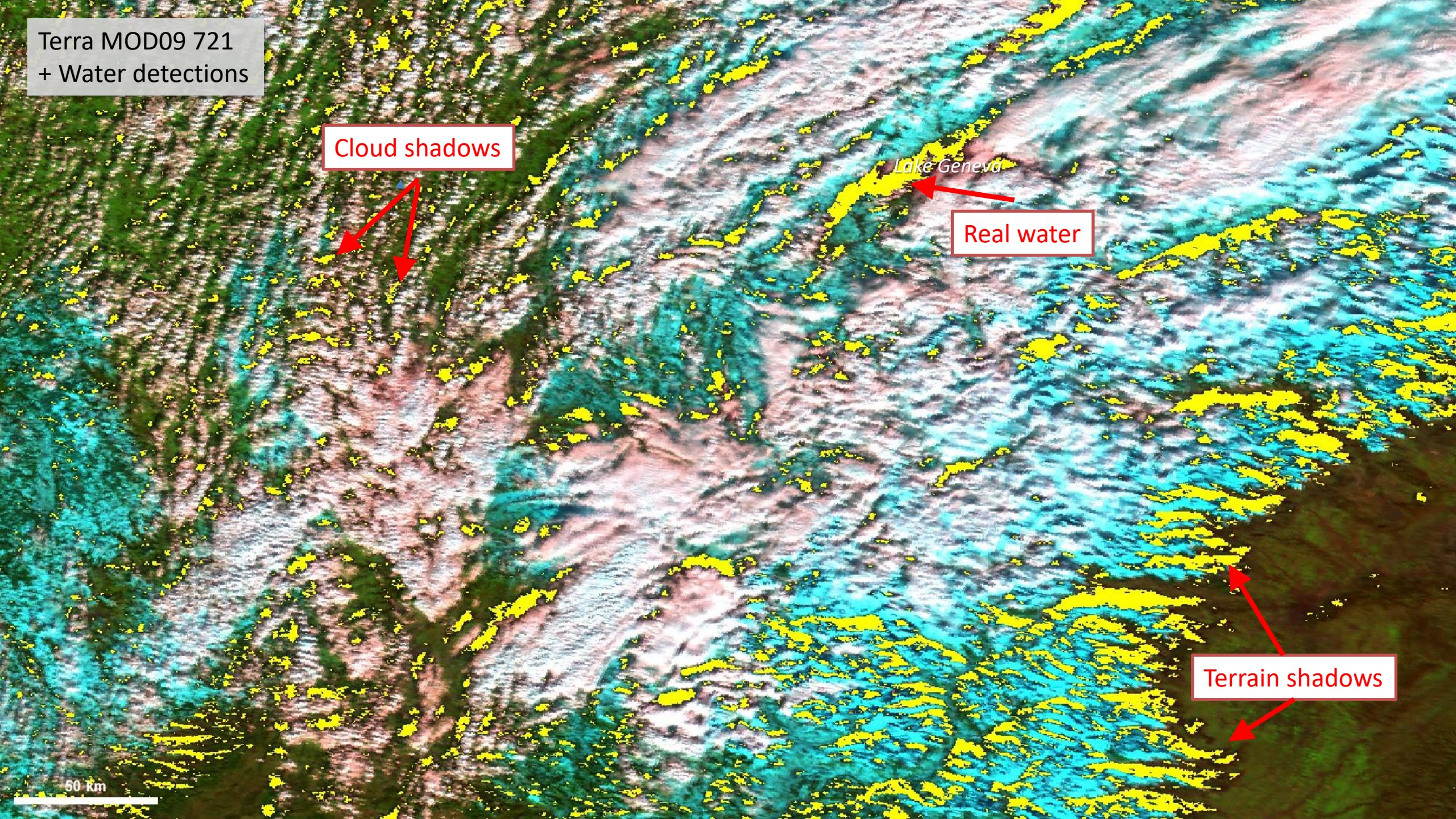
Terrain Shadow Masking Example:

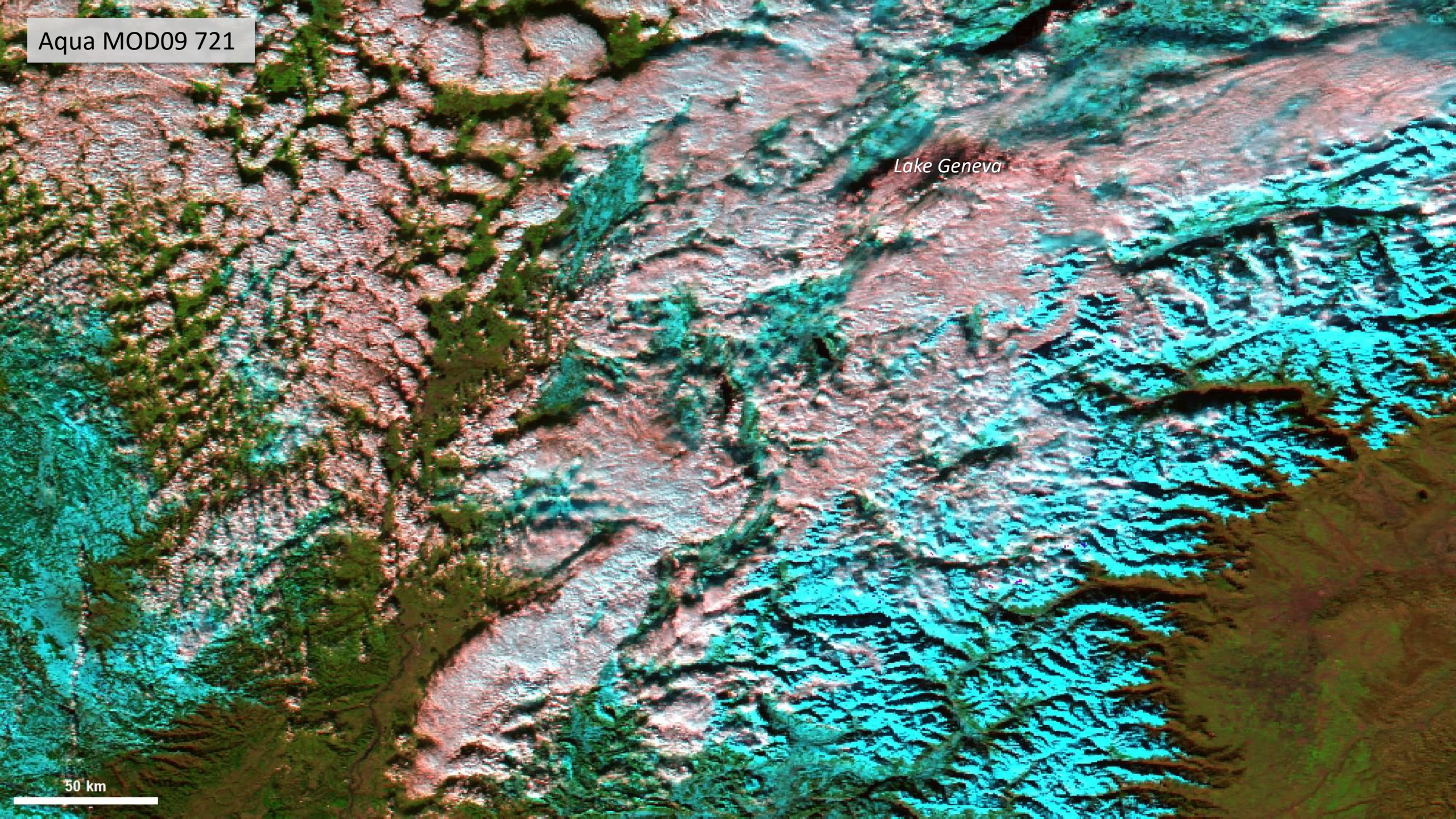
Alps – imagery basemap

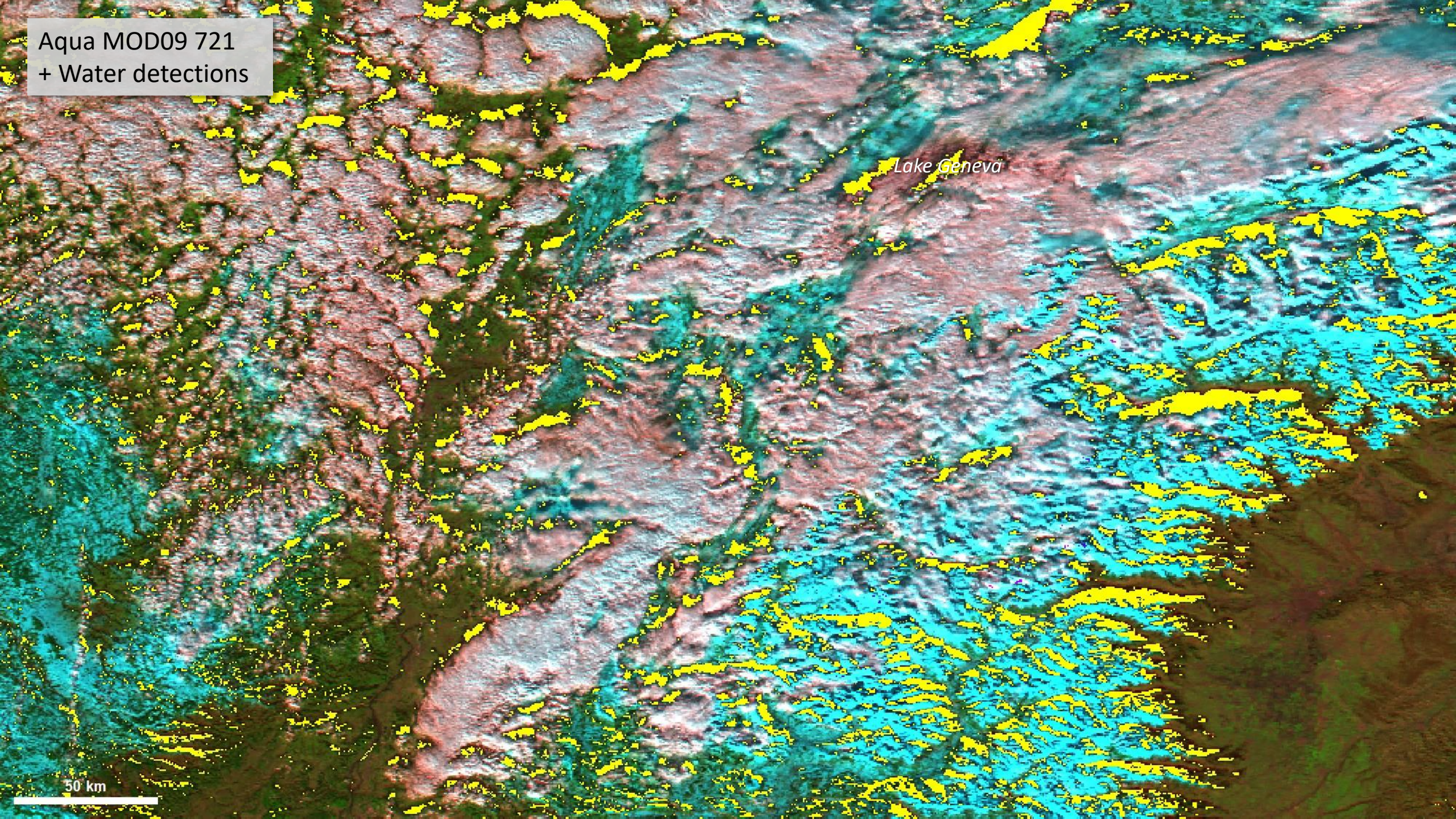


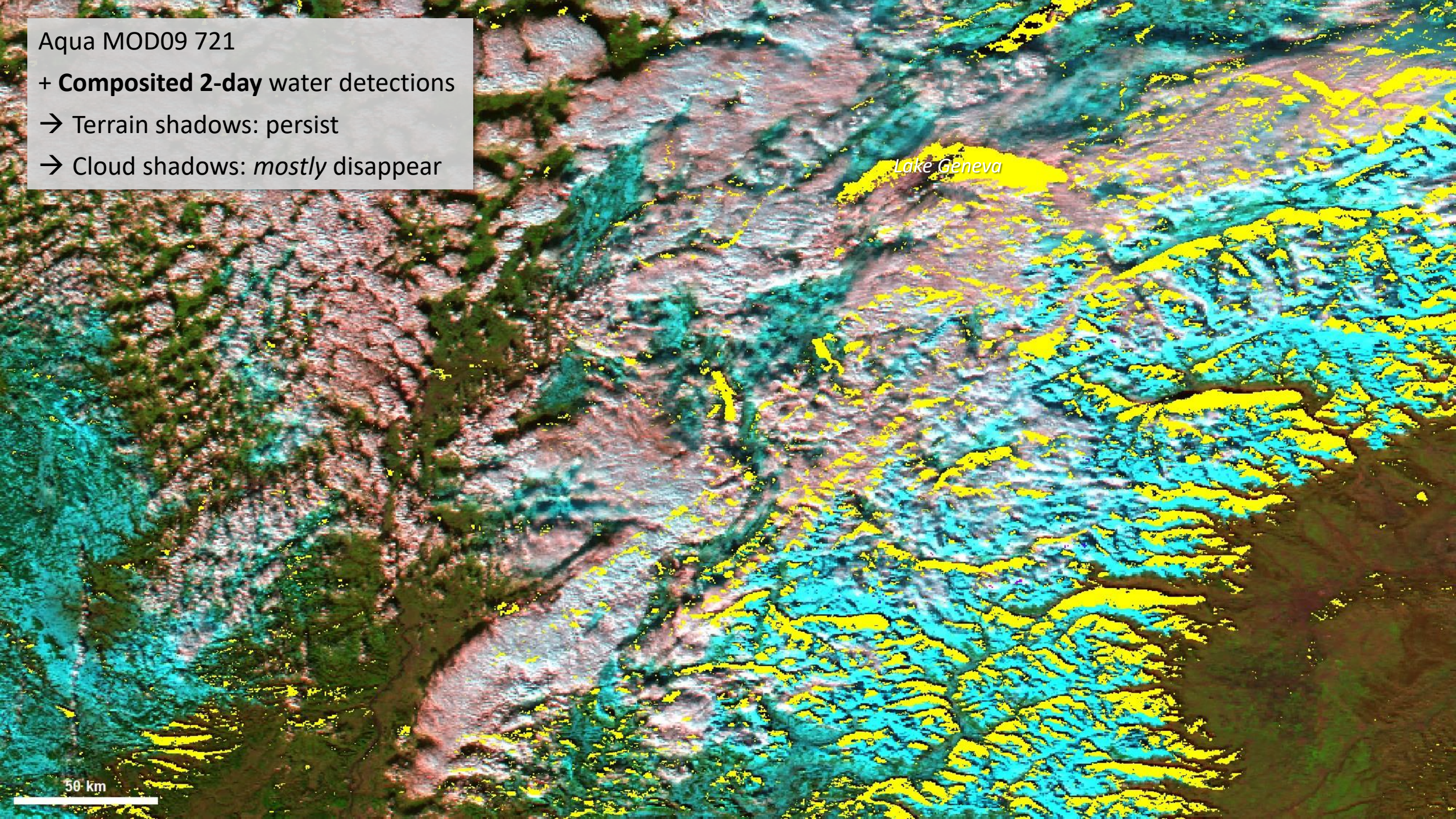
Example: Alps - terrain

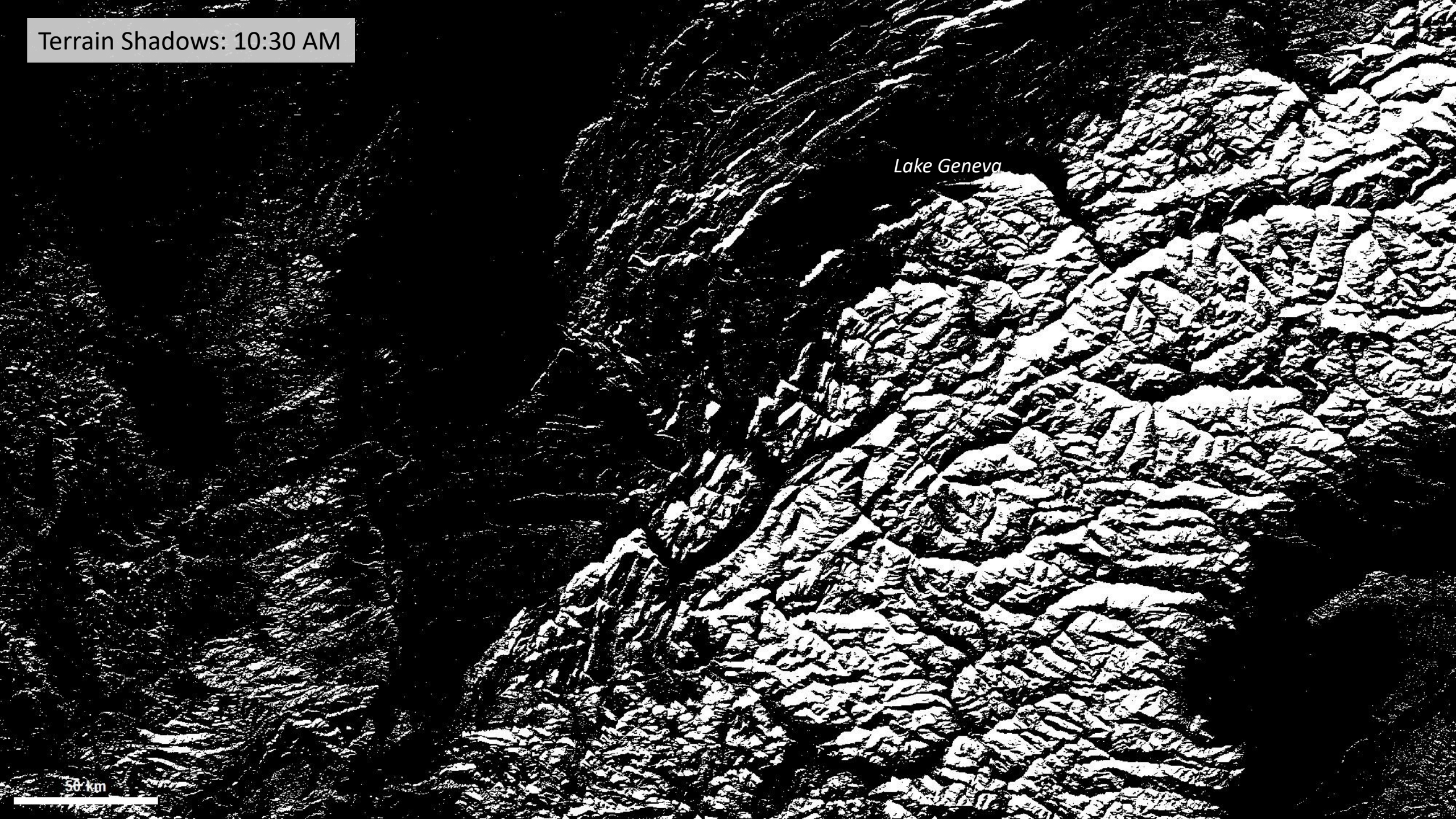

Terra MOD09 721
(Clouds + snow)
Lake Geneva
50 km

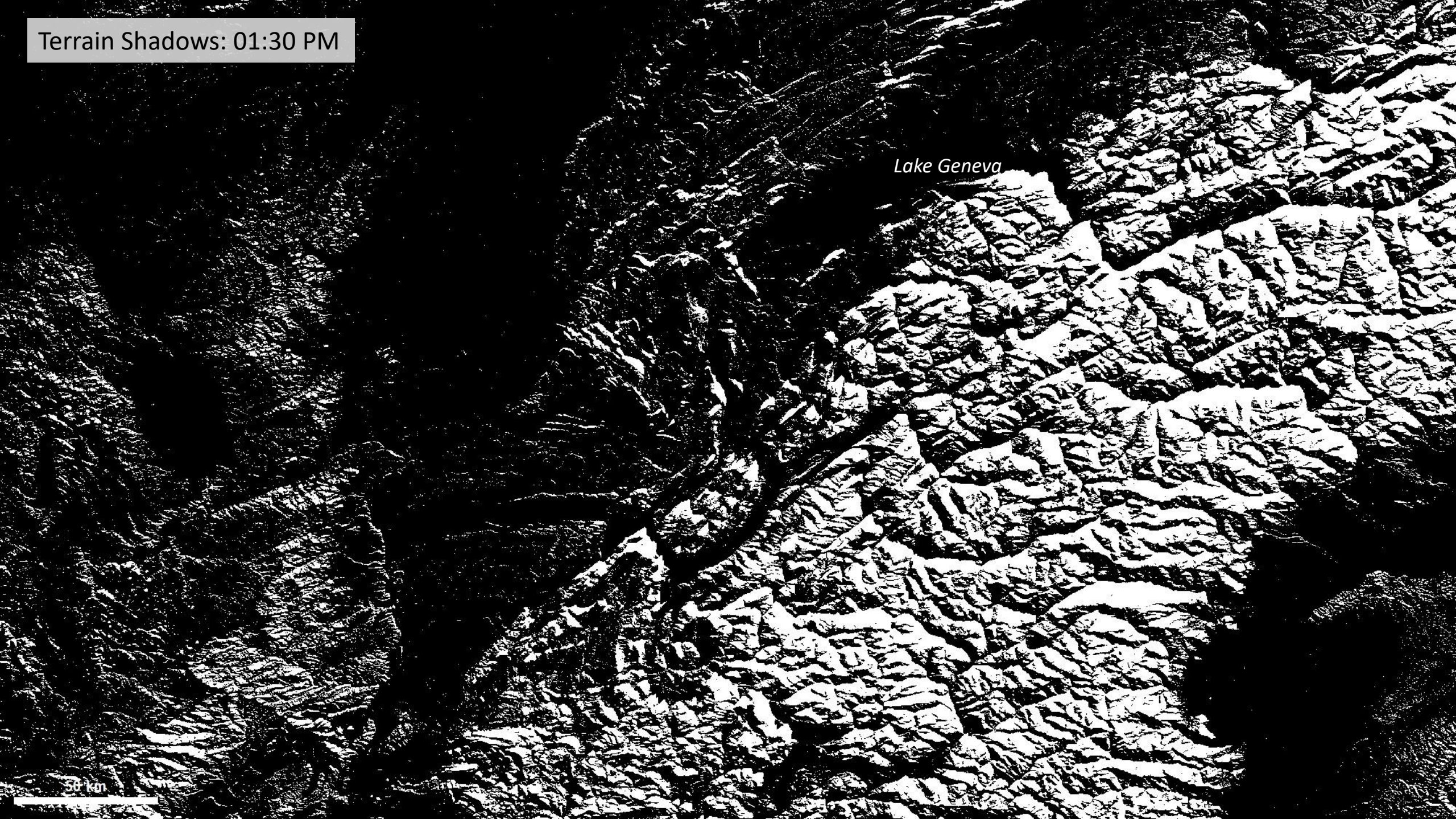

Terra MOD09 721
+ Water detections
Cloud shadows
Lake Geneva
Real water
Terrain shadows
50 km

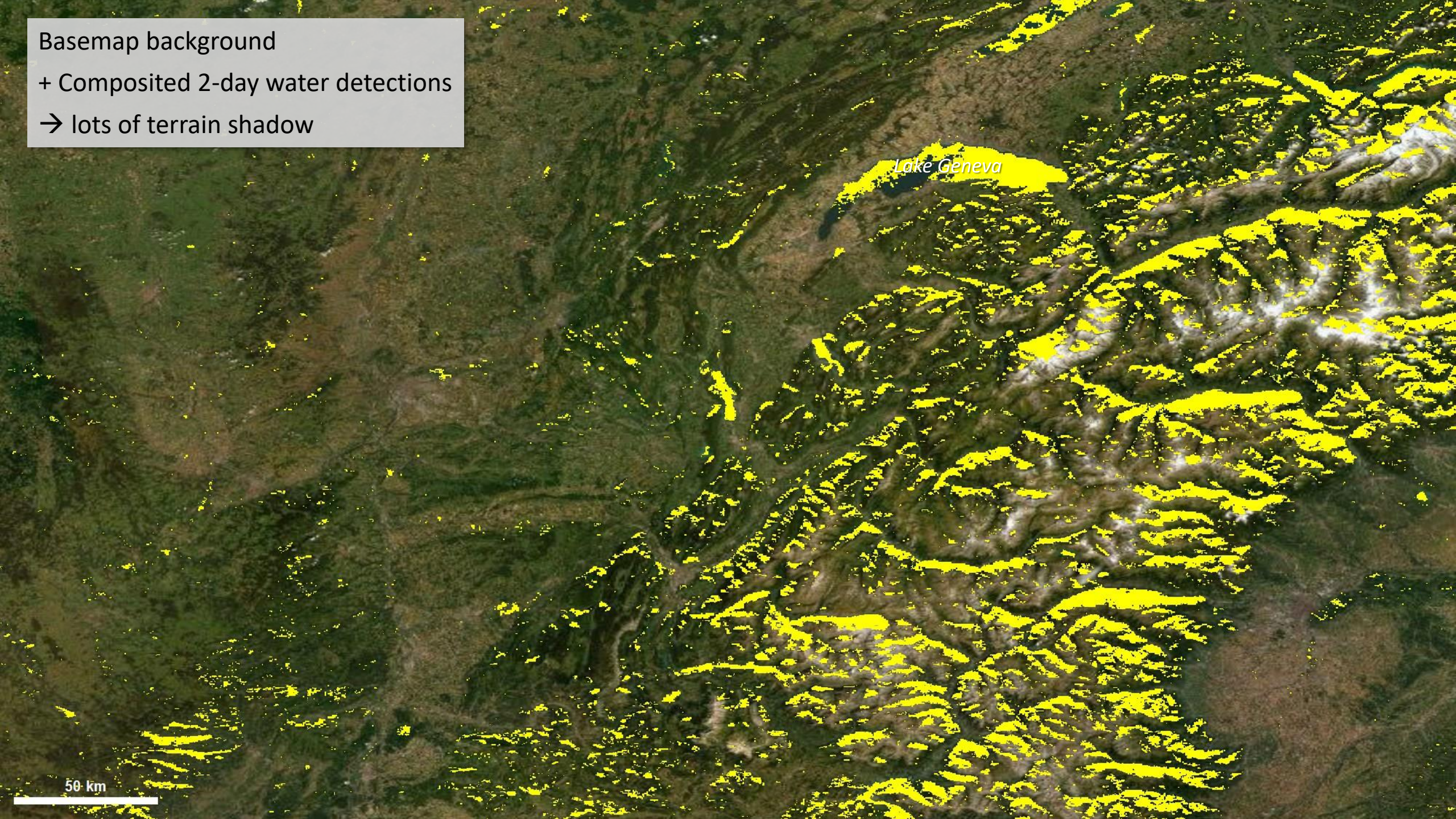

Aqua MOD09 721
Lake Geneva
50 km

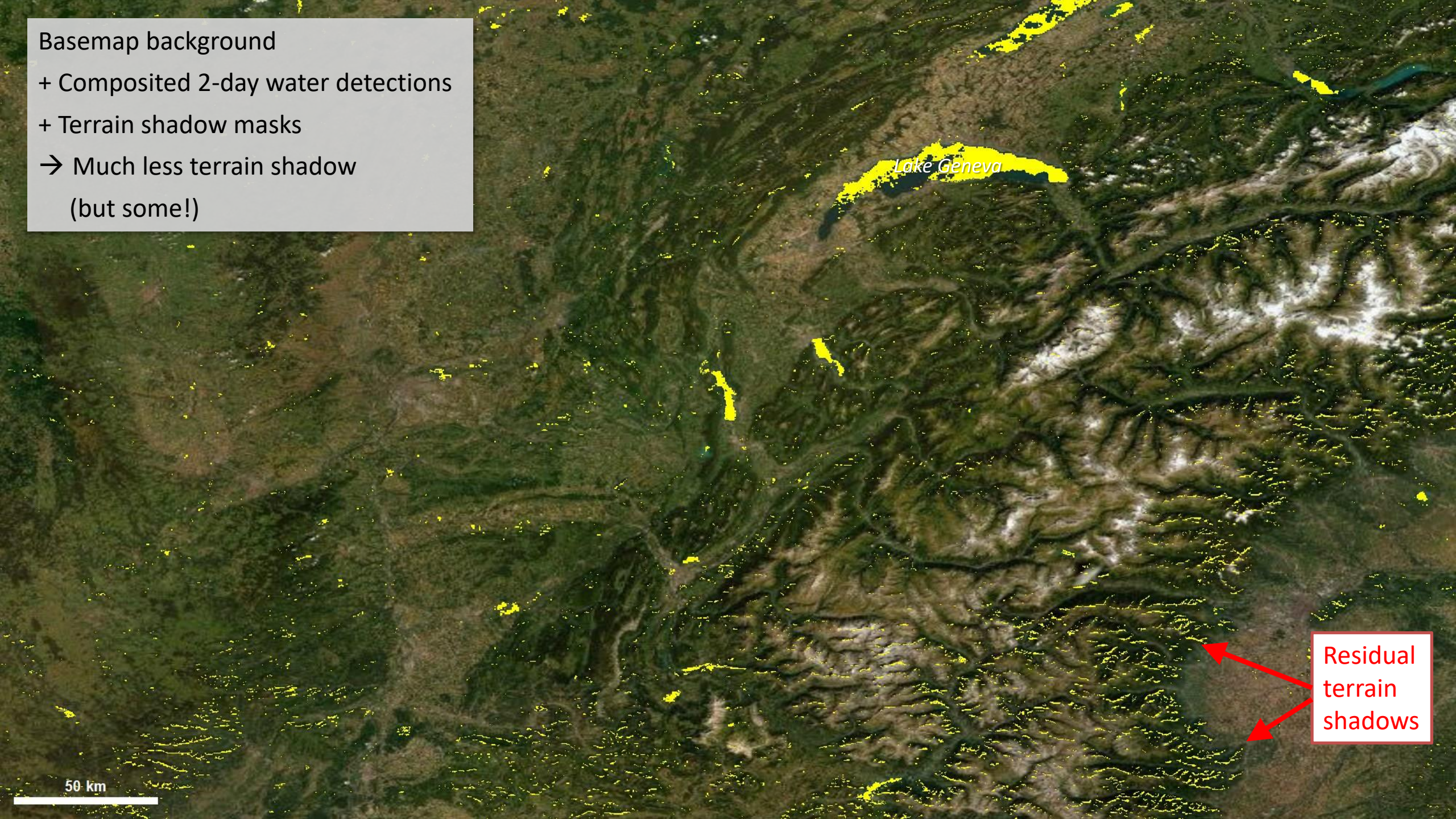

Aqua MOD09 721
+ Water detections
Lake Geneva
50 km

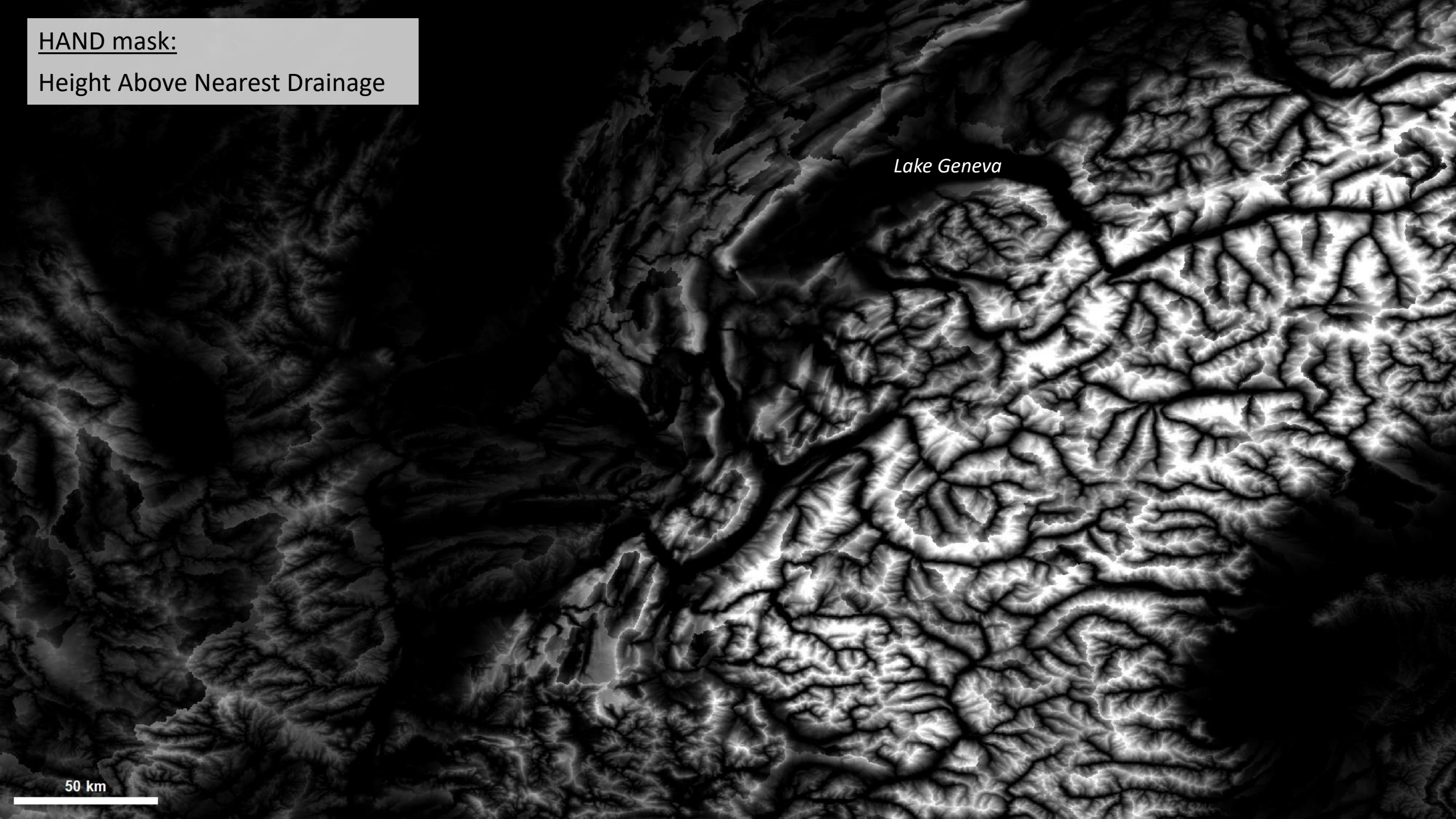

Aqua MOD09 721
+ **Composited 2-day** water detections
→ Terrain shadows: persist
→ Cloud shadows: *mostly* disappear
Lake Geneva
50 km

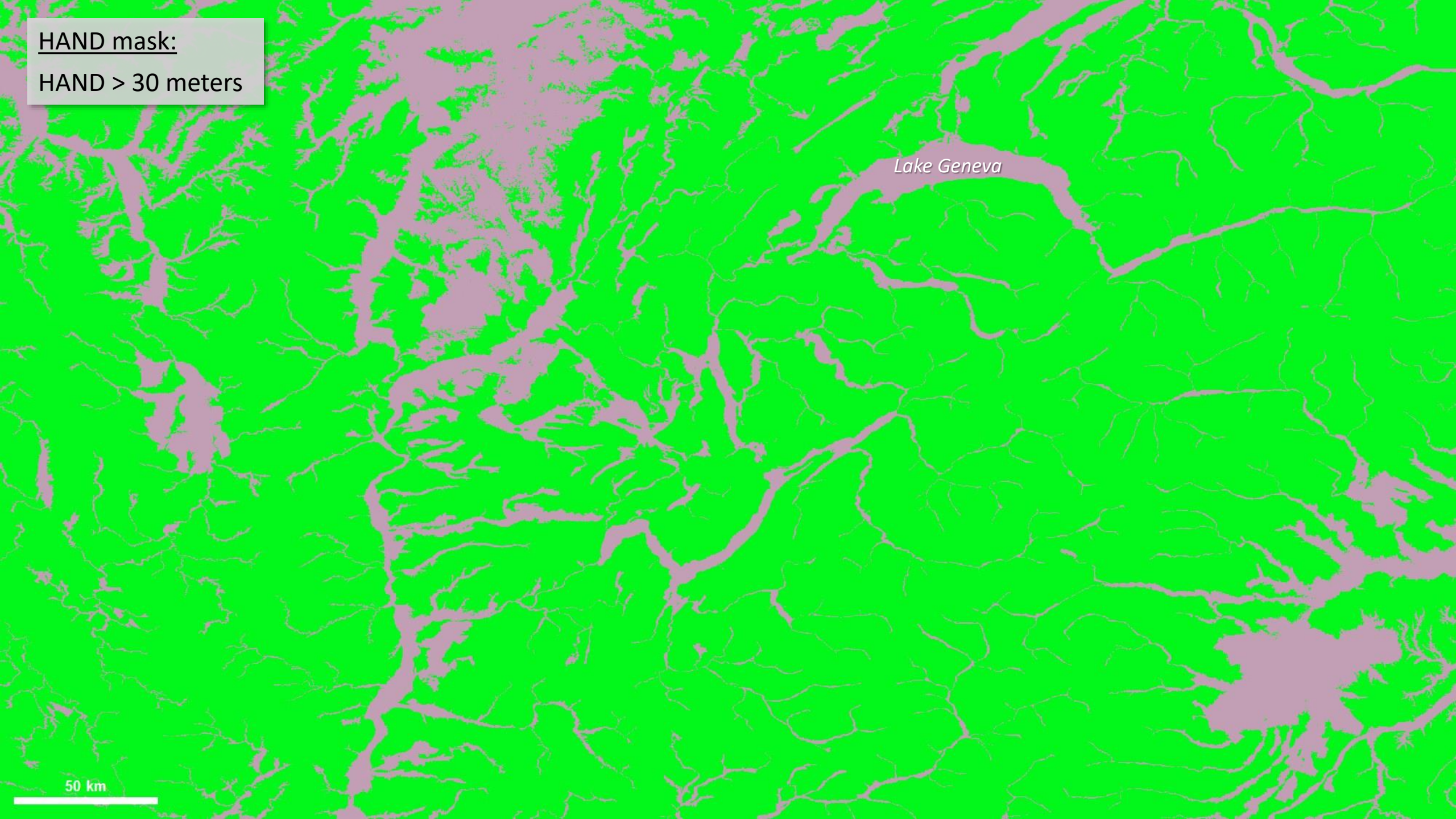

Terrain Shadows: 10:30 AM
Lake Geneva
50 km

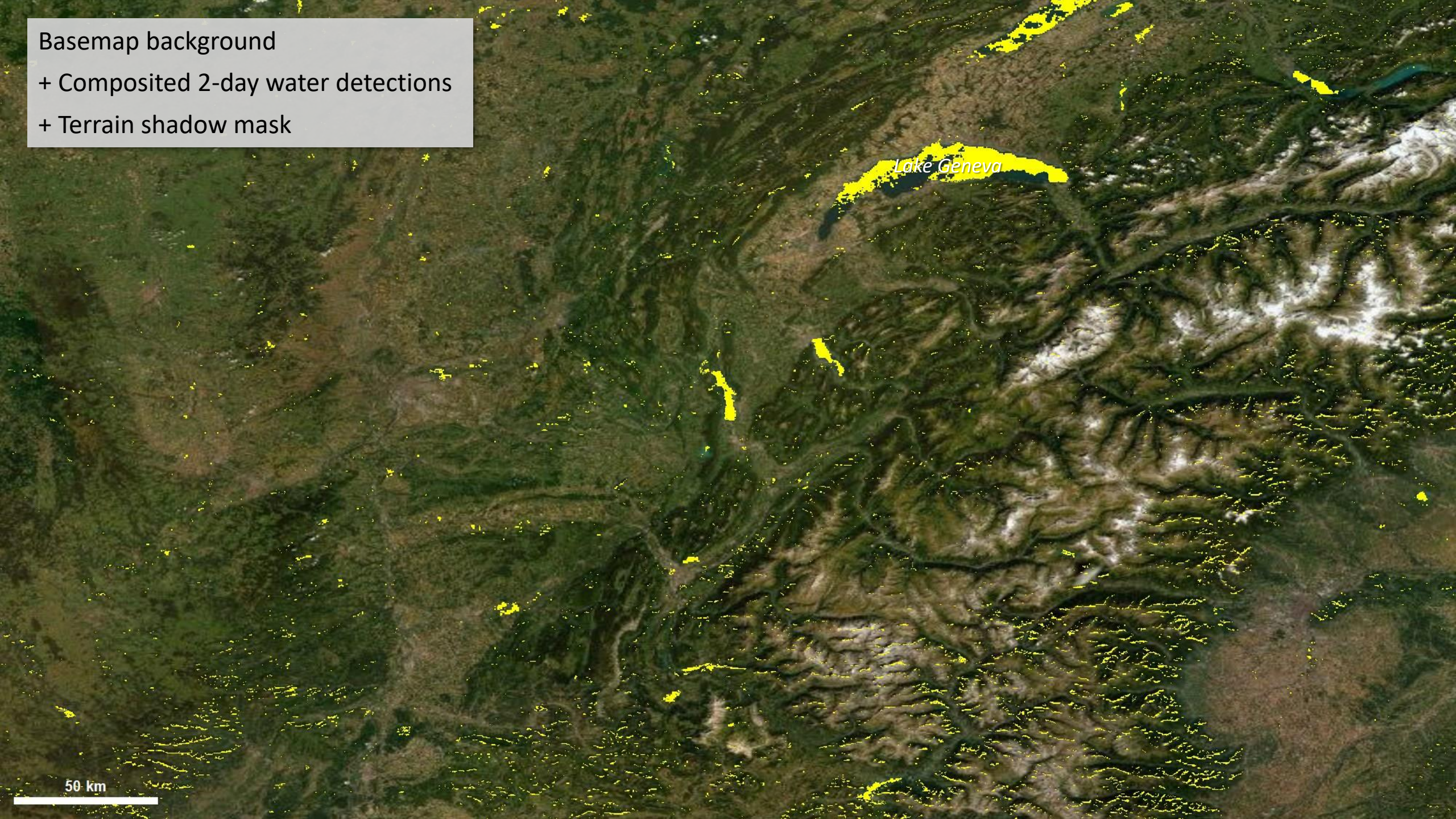

Terrain Shadows: 01:30 PM
Lake Geneva
50 km

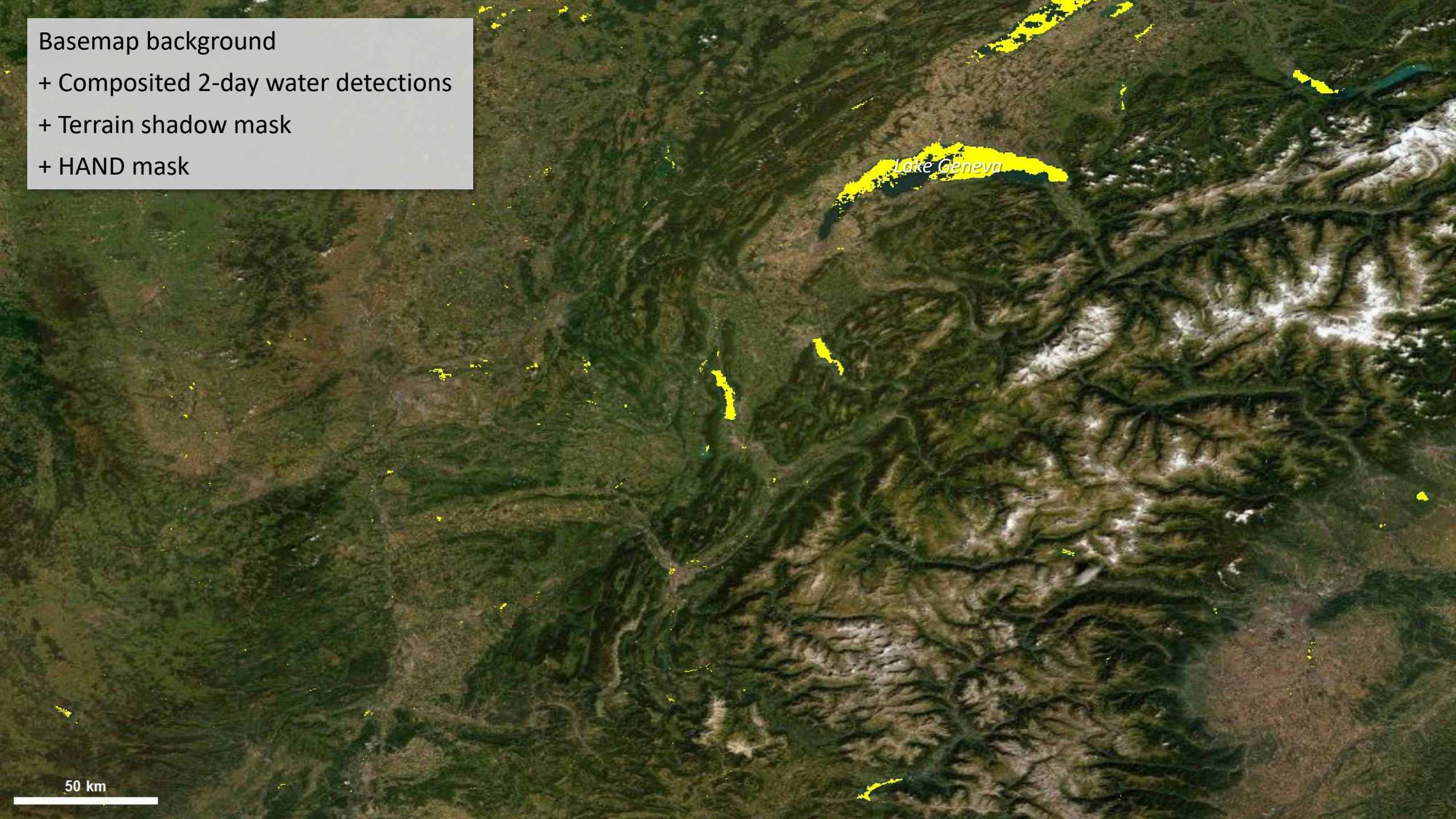

Basemap background
+ Composited 2-day water detections
→ lots of terrain shadow
Lake Geneva
50 km


Basemap background
+ Composited 2-day water detections
+ Terrain shadow masks
→ Much less terrain shadow
(but some!)
Lake Geneva
Residual terrain shadows
50 km


HAND mask:
Height Above Nearest Drainage
Lake Geneva
50 km

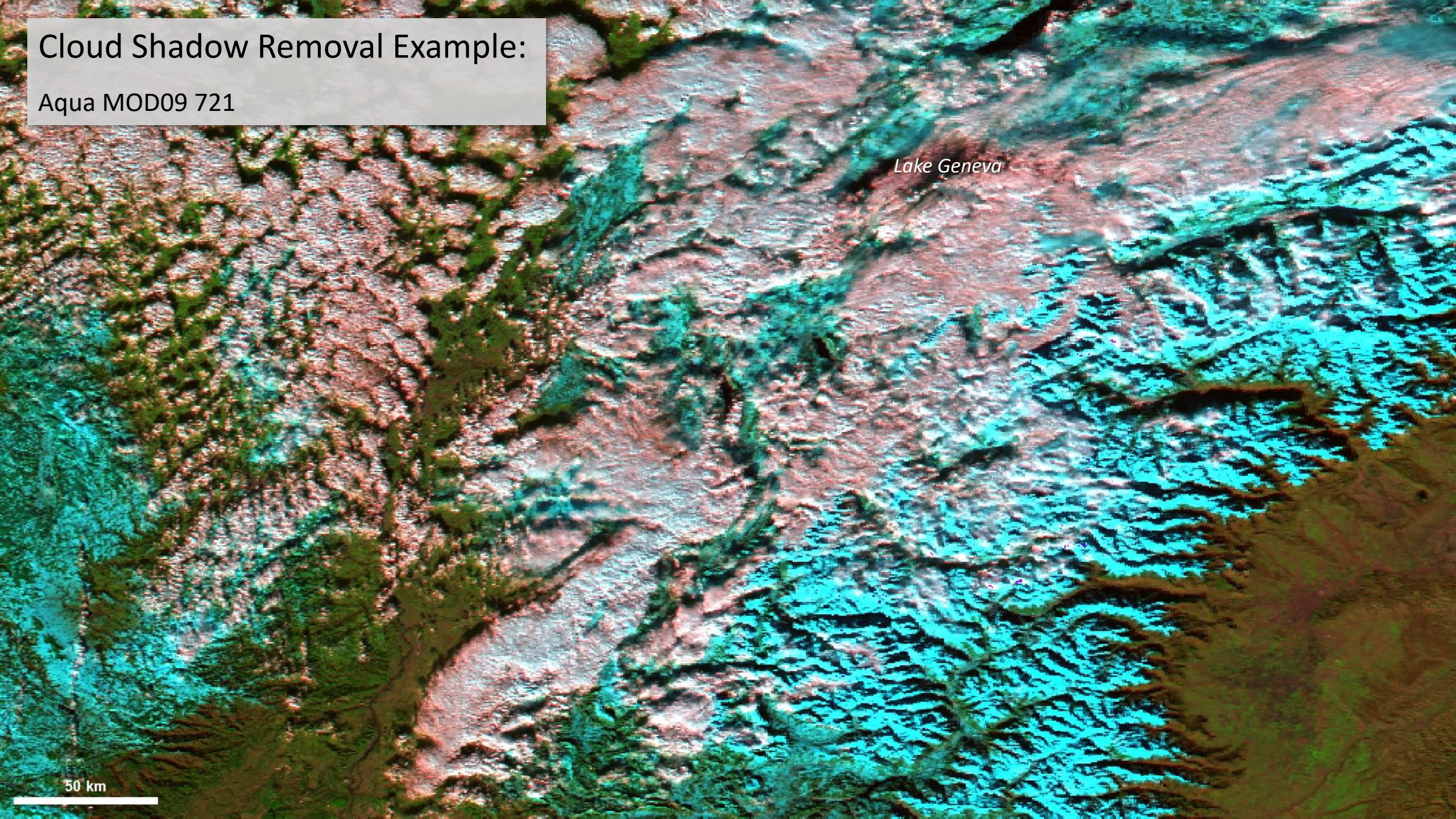

HAND mask:
HAND > 30 meters
Lake Geneva
50 km

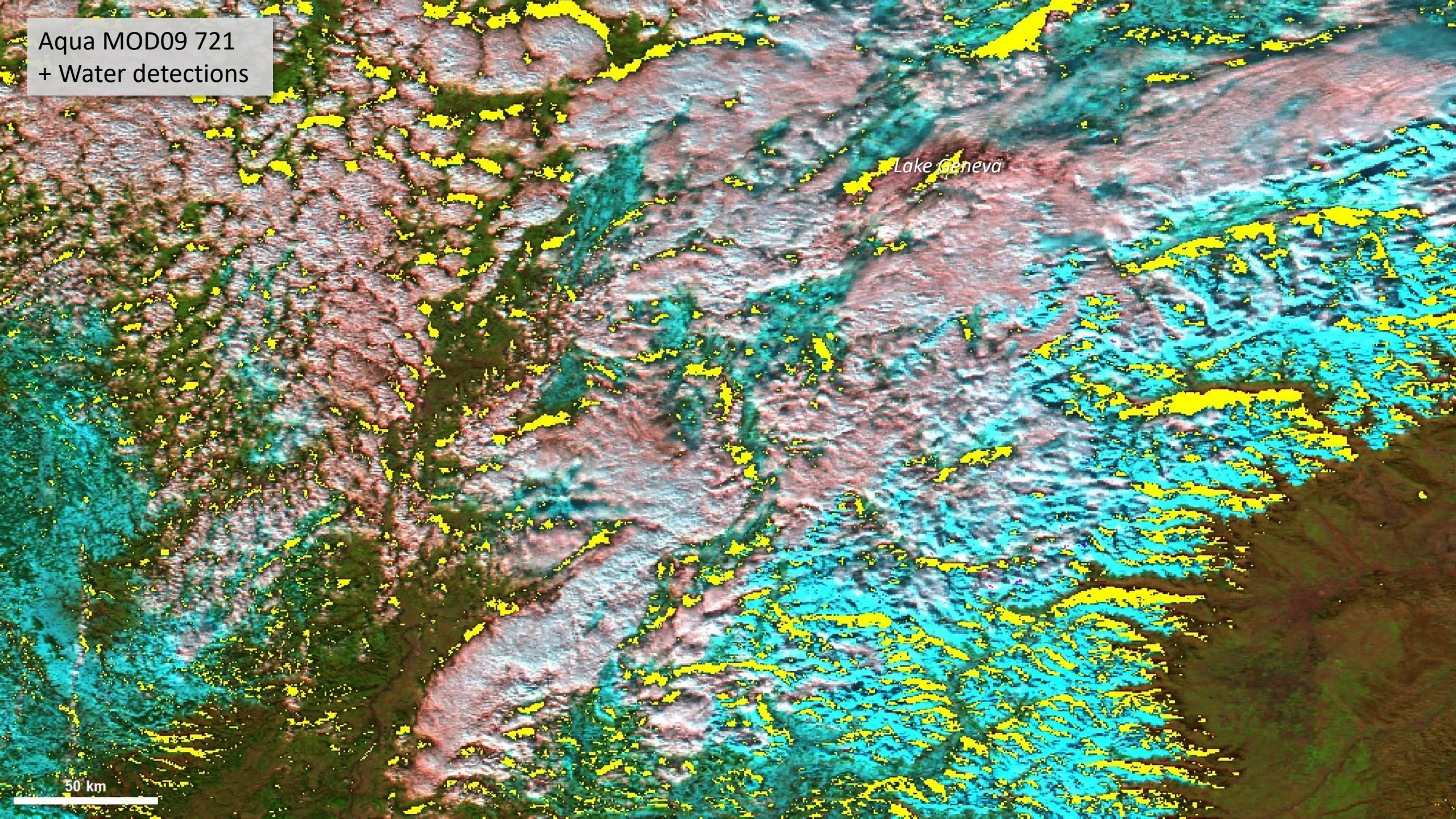

Basemap background
+ Composited 2-day water detections
+ Terrain shadow mask
Lake Geneva
50 km

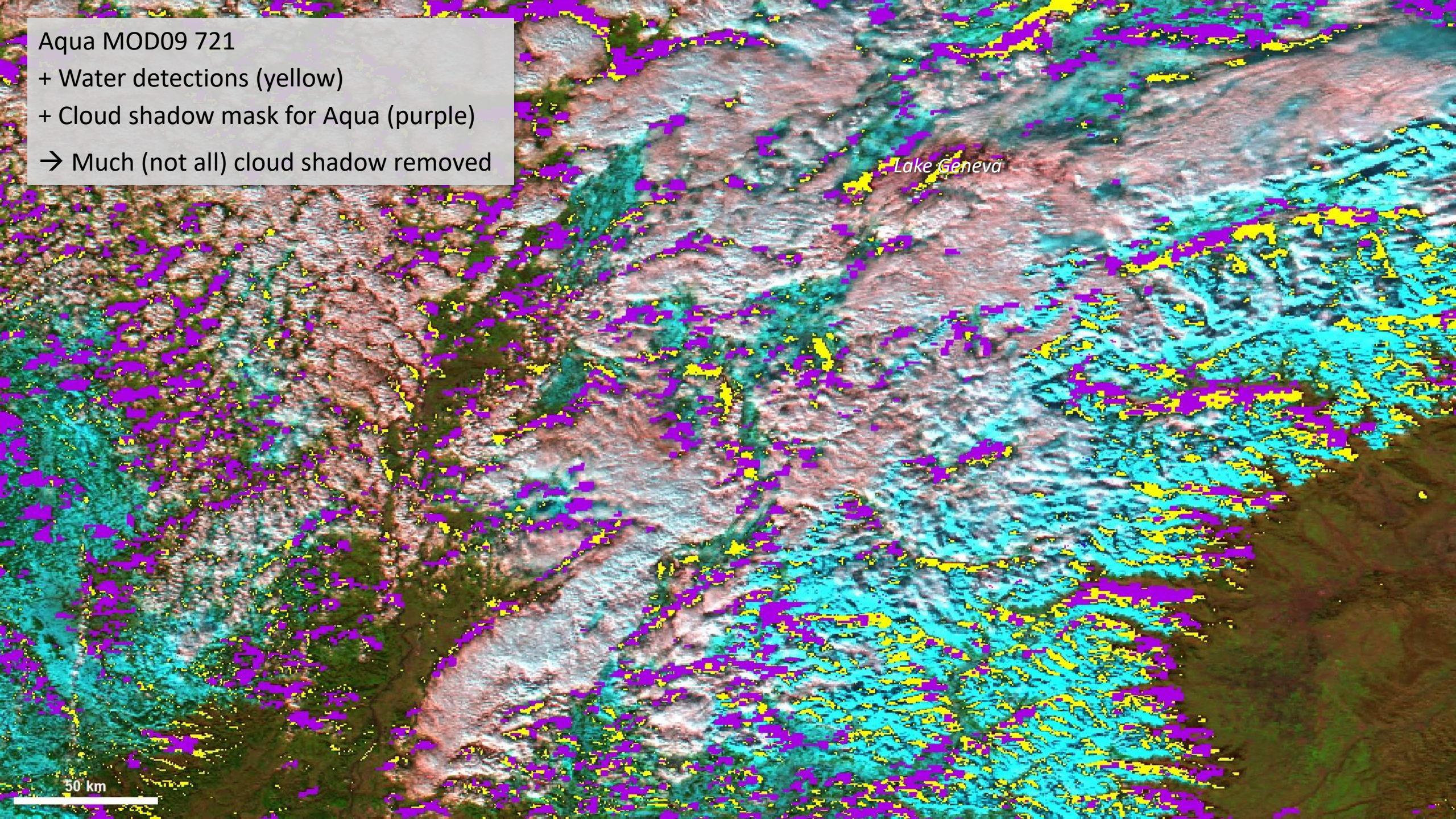

Basemap background
+ Composited 2-day water detections
+ Terrain shadow mask
+ HAND mask
Lake Geneva
50 km

Cloud Shadow Removal Example:

Aqua MOD09 721




Aqua MOD09 721
+ Water detections
Lake Geneva
50 km


Aqua MOD09 721
+ Water detections (yellow)
+ Cloud shadow mask for Aqua (purple)
→ Much (not all) cloud shadow removed
Lake Geneva
50 km

4. Determination of “flood”

- Compare detected to “reference water” = expected water
- Pre-LANCE: MOD44W static global water product
- LANCE: plan to generate our own from the flood product
  - Can be more easily updated to reflect real surface water changes
  - Pending backprocessing (after LANCE NRT processing operational)
  - Interim: use our existing reference water (original MOD44W)

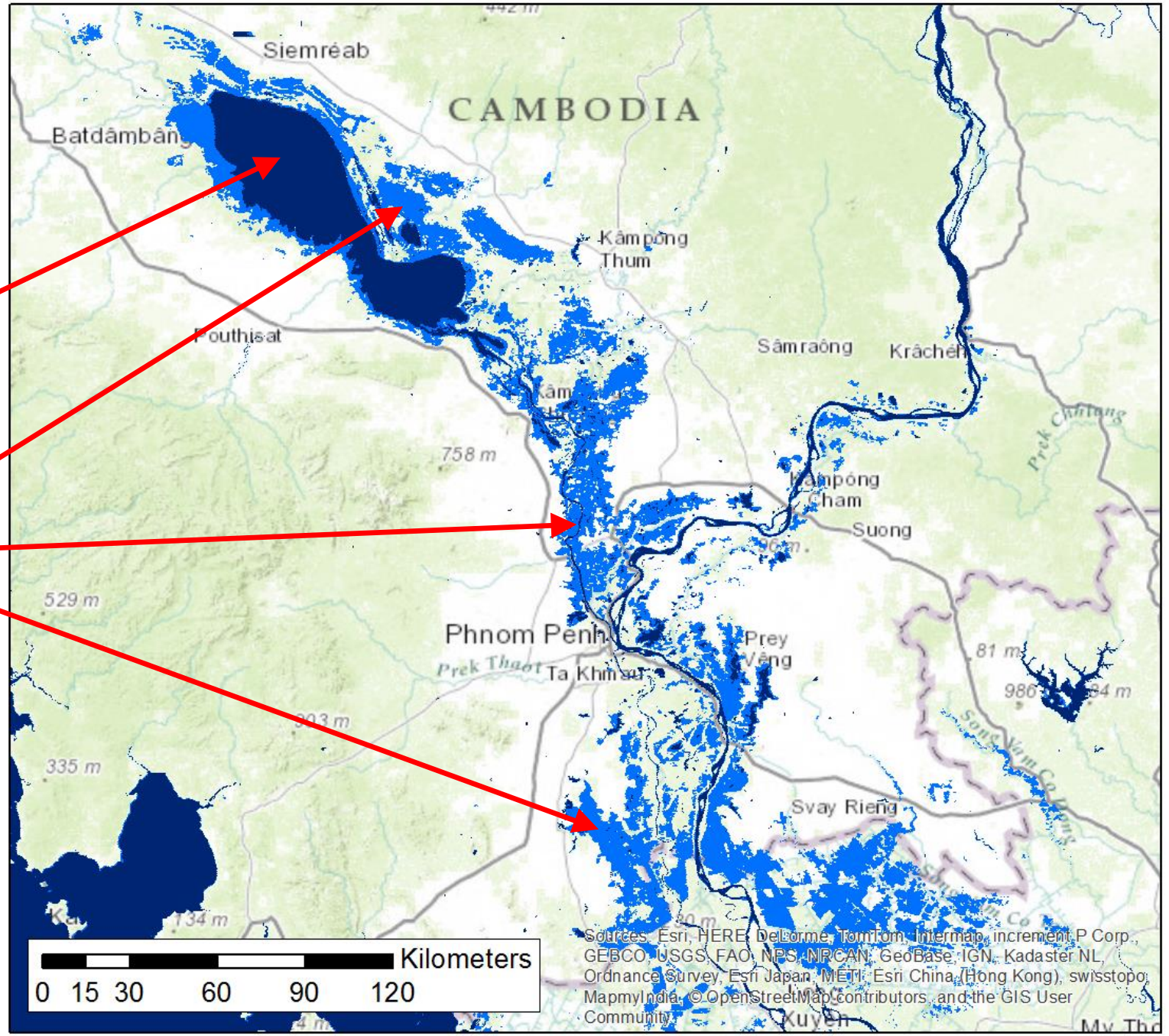
- New Feature: “Recurring flood”
  - Using product archive, can identify regions with regular flooding
  - Will be marked differently in flood product: “recurring flood”

Example: (Cambodia)

Permanent water vs recurring flooding

Reference water

Recurring flood

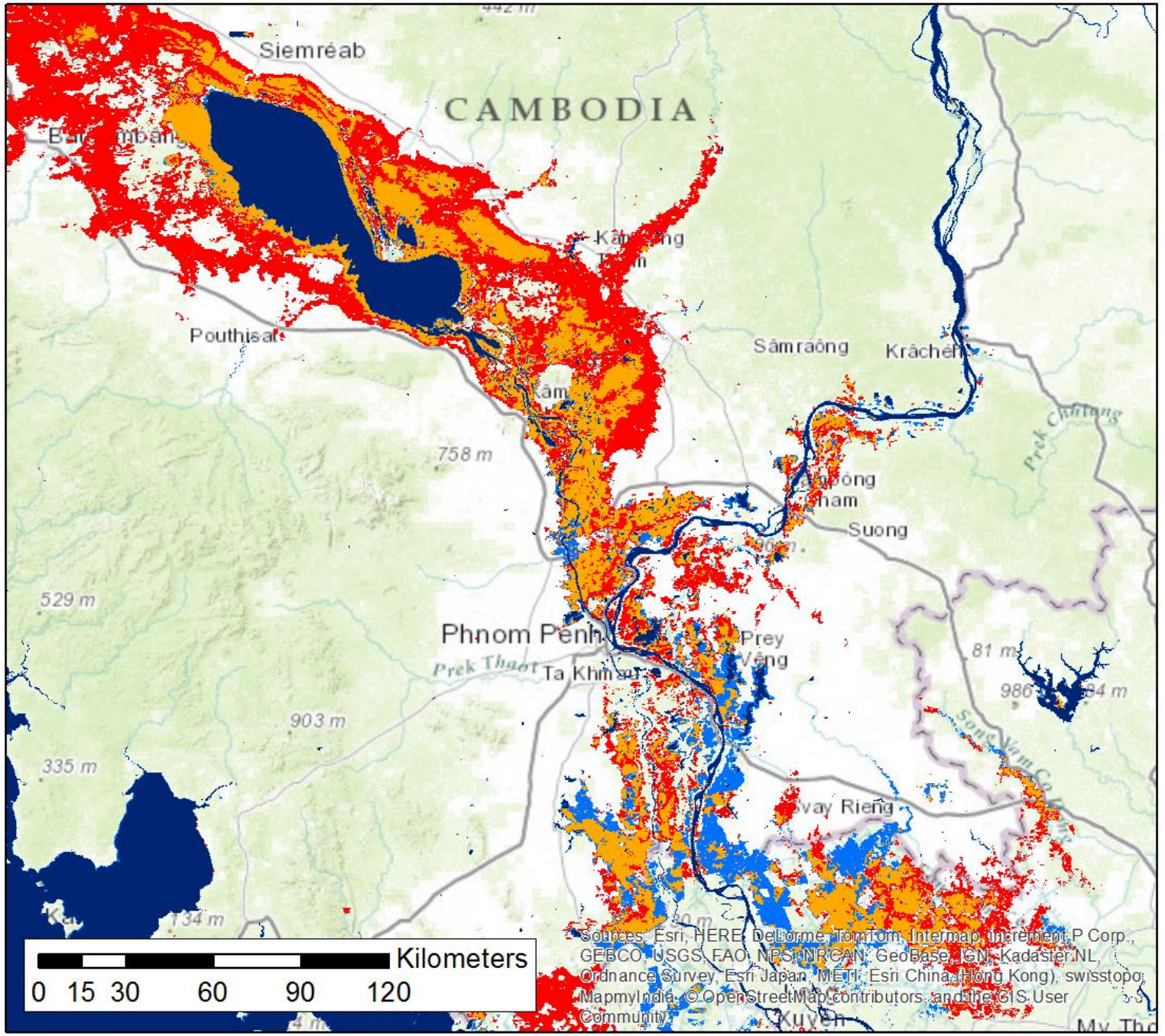


Example: (Cambodia)

Applied to Oct 2013 flood product

Differentiates:

- Recurring flood (orange)
- Flood (red)



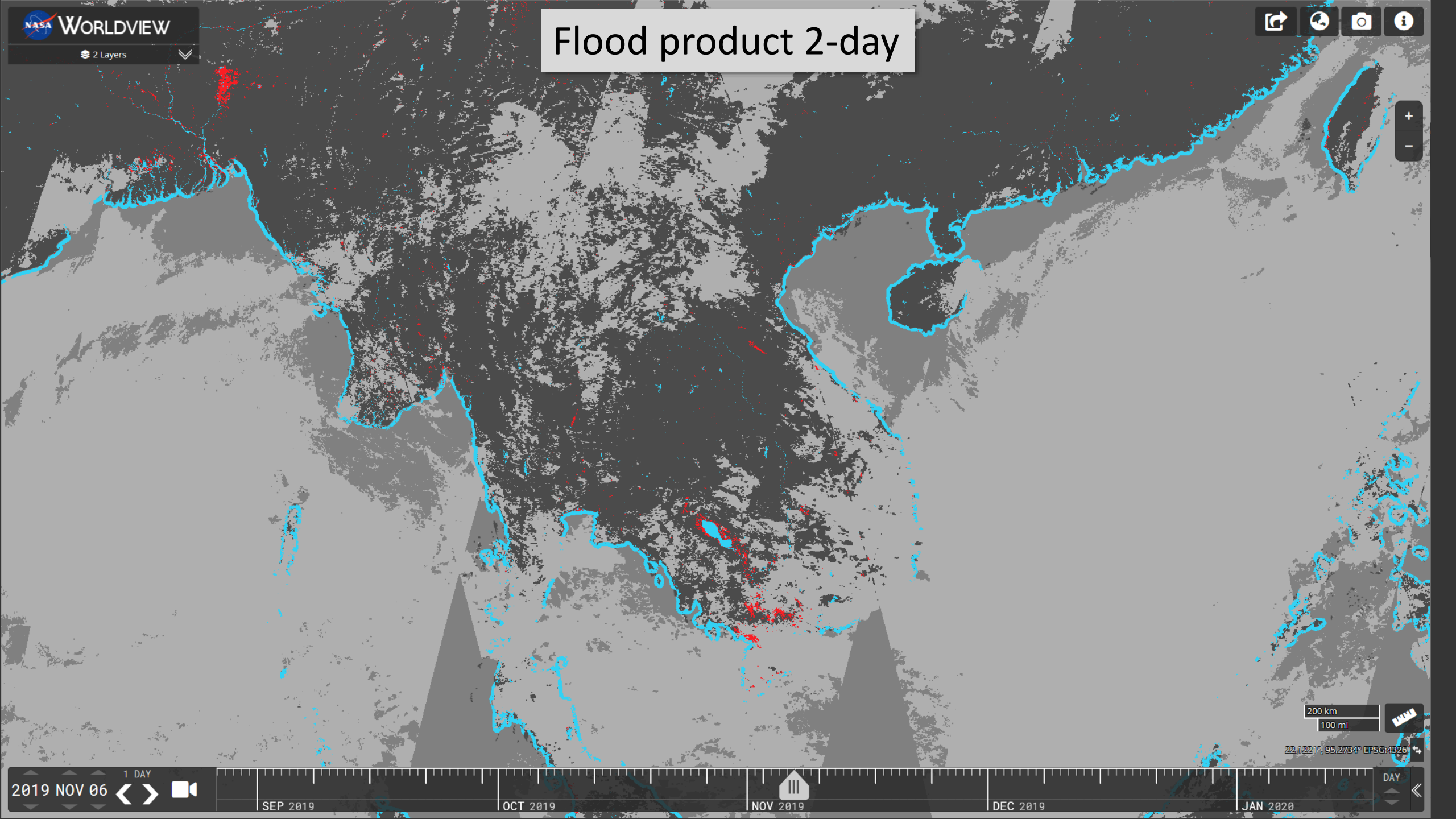
(11-Oct-2013, 2-day product)

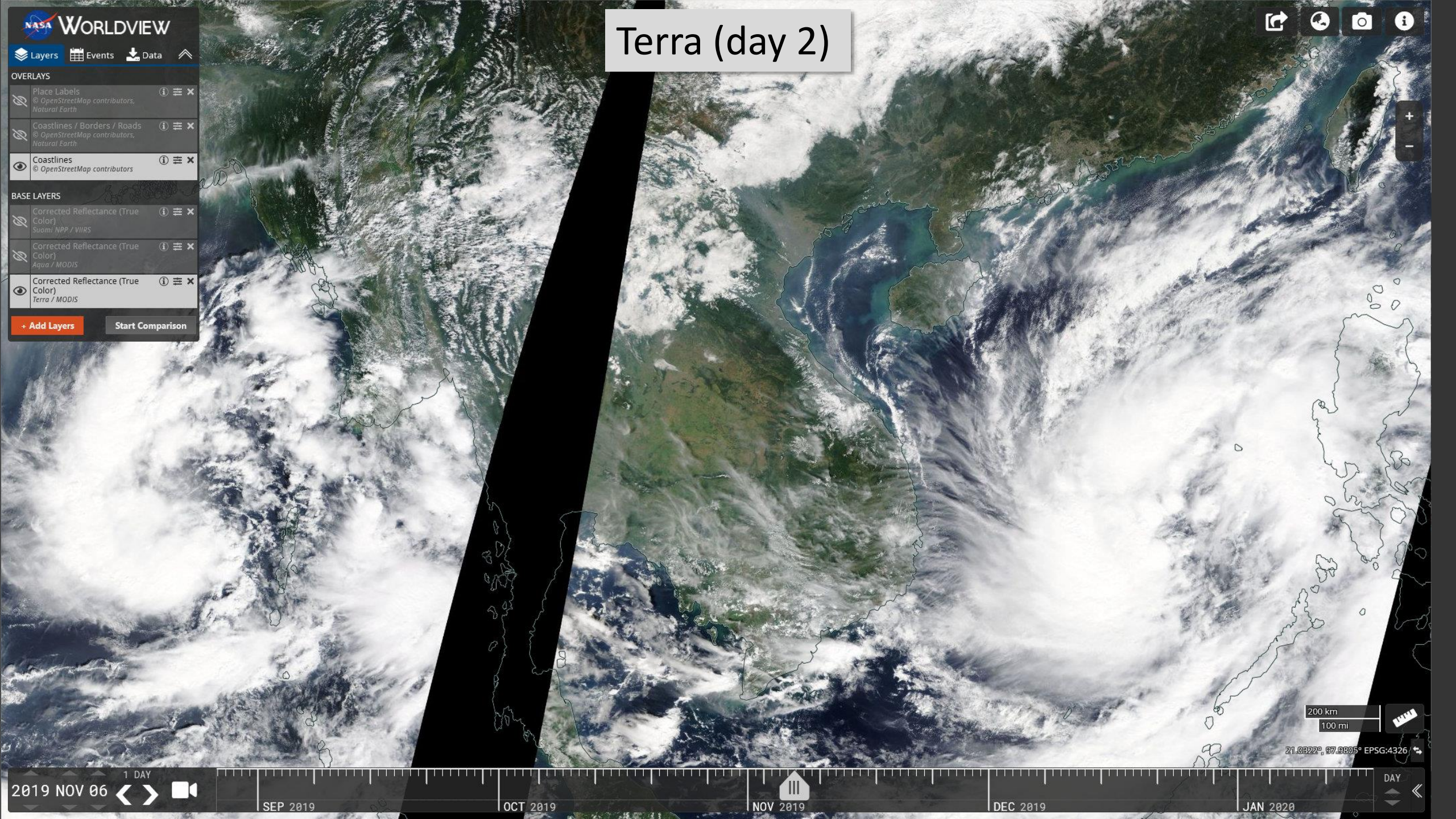
LANCE Improvements: ESDIS/Worldview browsing

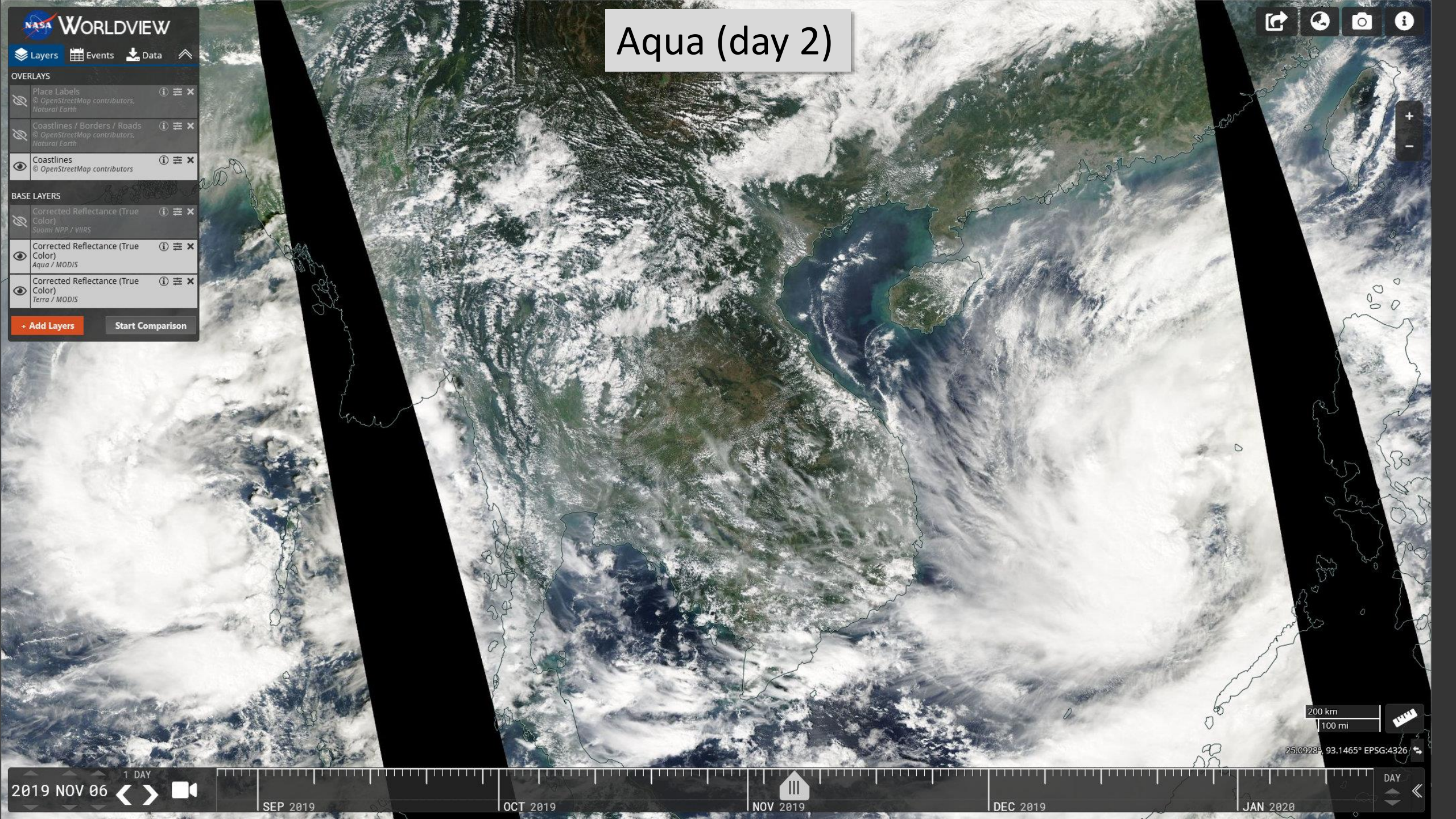
https://worldview.earthdata.nasa.gov

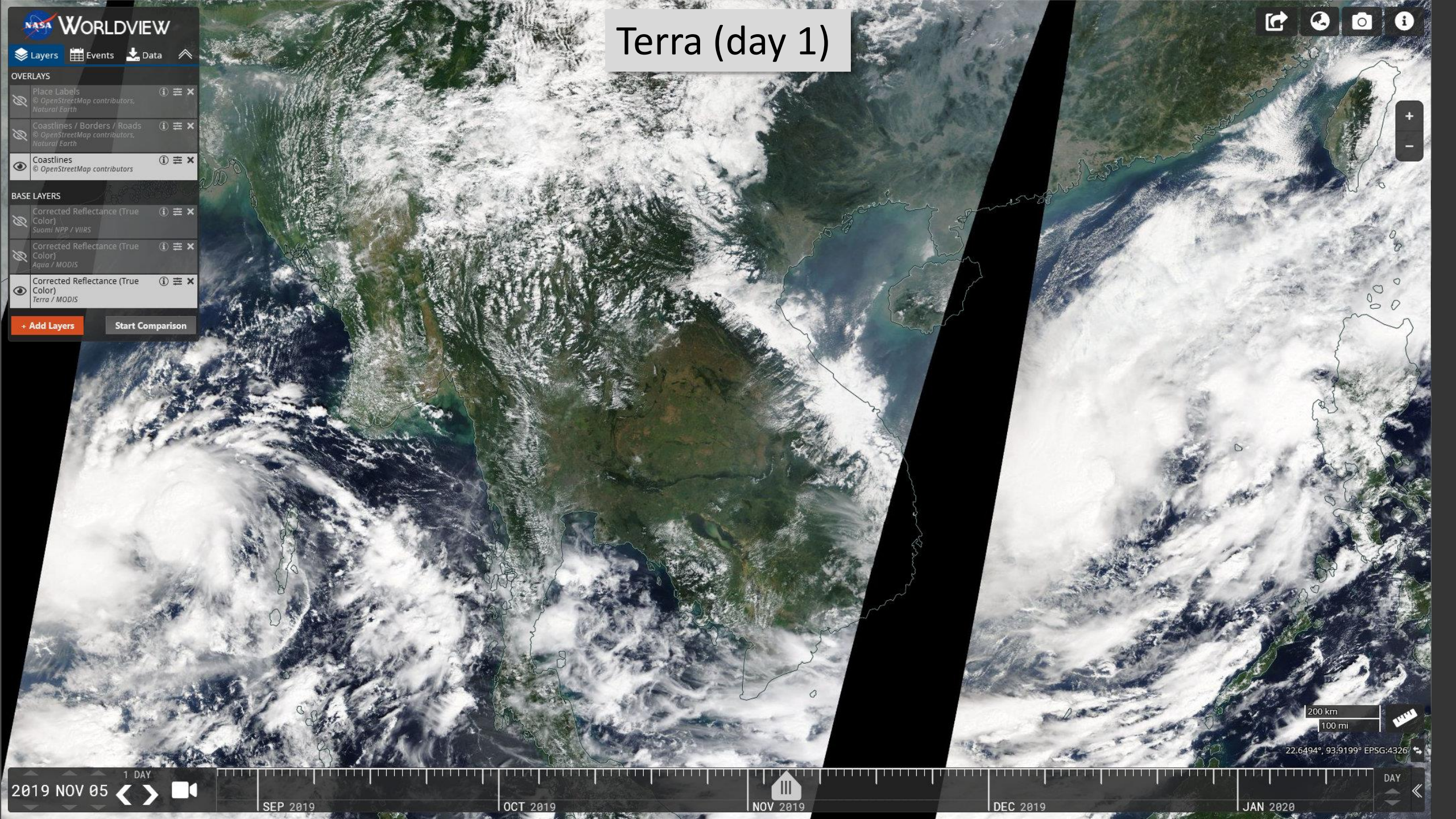
- Seamless browsing across 10x10 degree product tiles
- Easily follow flood progression over time
- Compare to past events
- Check optical imagery for clouds (“Can I use the 1-day product?”)
  - Need to check *all* contributing imagery (Terra + Aqua over 1, 2, or 3 days)

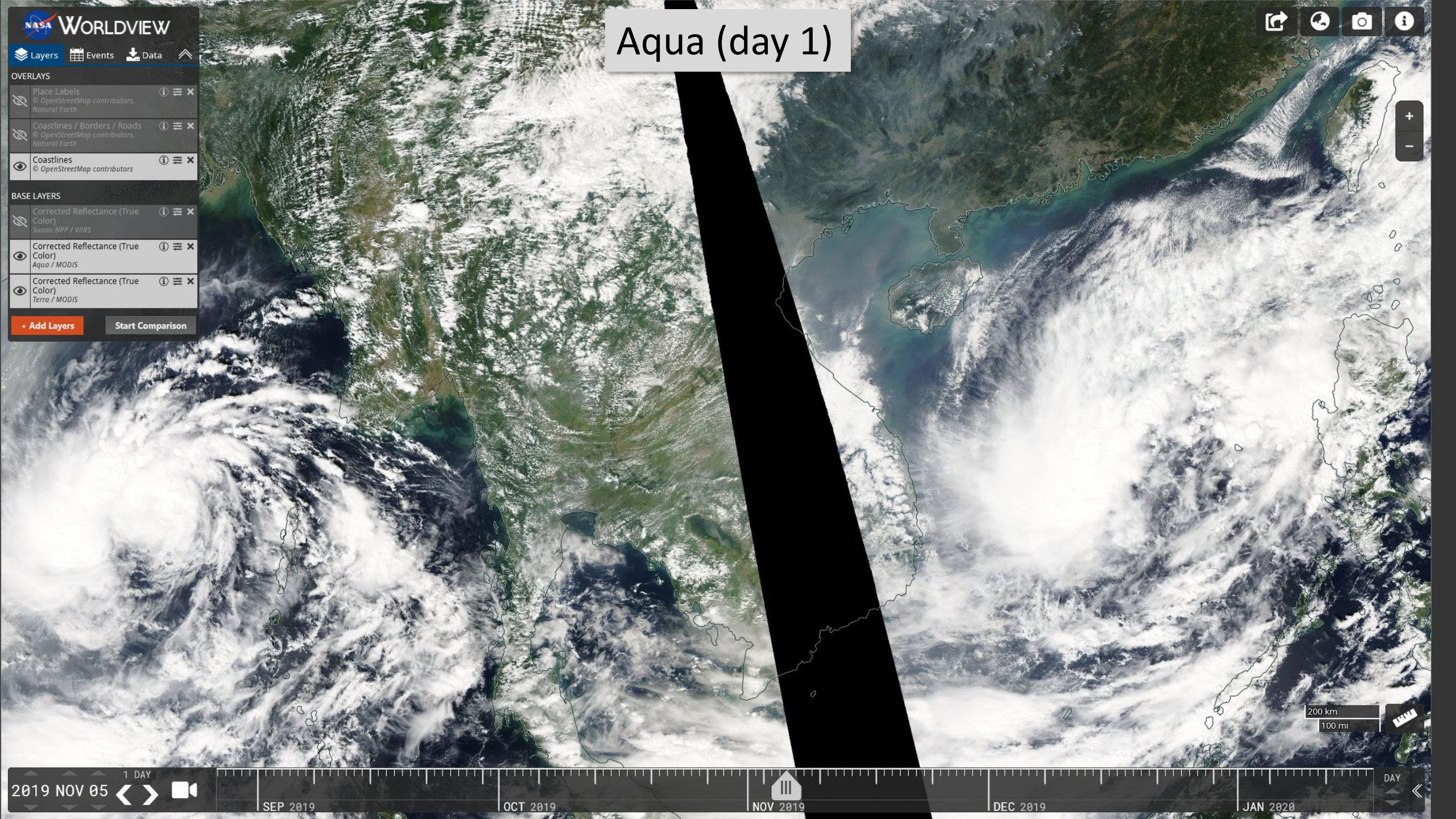
  → Not difficult in Worldview

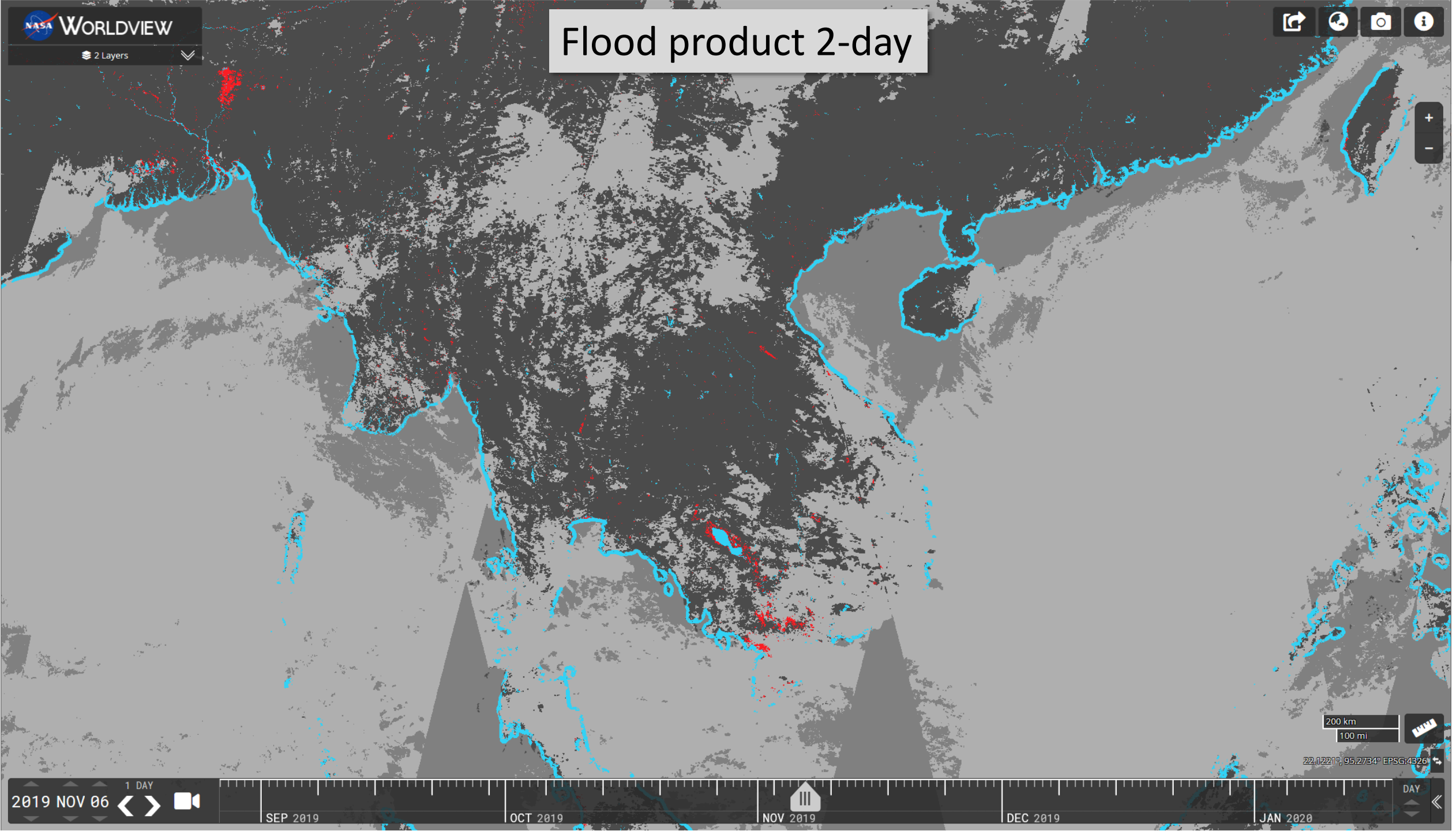

WORLDVIEW
2 Layers
Flood product 2-day
200 km
100 mi
22.1221°, 95.2734° EPSG:4326
1 DAY
2019 NOV 06
SEP 2019
OCT 2019
NOV 2019
DEC 2019
JAN 2020
DAY


NASA WORLDVIEW
Layers
Events
Data
OVERLAYS
Place Labels
© OpenStreetMap contributors, Natural Earth
Coastlines / Borders / Roads
© OpenStreetMap contributors, Natural Earth
Coastlines
© OpenStreetMap contributors
BASE LAYERS
Corrected Reflectance (True Color)
Suomi NPP / VIIRS
Corrected Reflectance (True Color)
Aqua / MODIS
Corrected Reflectance (True Color)
Terra / MODIS
+ Add Layers
Start Comparison
Terra (day 2)
200 km
100 mi
21.0322°, 97.9805° EPSG:4326
1 DAY
2019 NOV 06
SEP 2019
OCT 2019
NOV 2019
DEC 2019
JAN 2020
DAY


Aqua (day 2)
NASA WORLDVIEW
Layers
Events
Data
OVERLAYS
Place Labels
© OpenStreetMap contributors, Natural Earth
Coastlines / Borders / Roads
© OpenStreetMap contributors, Natural Earth
Coastlines
© OpenStreetMap contributors
BASE LAYERS
Corrected Reflectance (True Color)
Suomi NPP / VIIRS
Corrected Reflectance (True Color)
Aqua / MODIS
Corrected Reflectance (True Color)
Terra / MODIS
+ Add Layers
Start Comparison
200 km
100 mi
25.0928°, 93.1465° EPSG:4326
2019 NOV 06
1 DAY
SEP 2019
OCT 2019
NOV 2019
DEC 2019
JAN 2020
DAY


Terra (day 1)
NASA WORLDVIEW
Layers
Events
Data
OVERLAYS
Place Labels
© OpenStreetMap contributors, Natural Earth
Coastlines / Borders / Roads
© OpenStreetMap contributors, Natural Earth
Coastlines
© OpenStreetMap contributors
BASE LAYERS
Corrected Reflectance (True Color)
Suomi NPP / VIIRS
Corrected Reflectance (True Color)
Aqua / MODIS
Corrected Reflectance (True Color)
Terra / MODIS
+ Add Layers
Start Comparison
200 km
100 mi
22.6494°, 93.9199° EPSG:4326
1 DAY
2019 NOV 05
SEP 2019
OCT 2019
NOV 2019
DEC 2019
JAN 2020
DAY


Aqua (day 1)
NASA WORLDVIEW
Layers
Events
Data
OVERLAYS
Place Labels
© OpenStreetMap contributors, Natural Earth
Coastlines / Borders / Roads
© OpenStreetMap contributors, Natural Earth
Coastlines
© OpenStreetMap contributors
BASE LAYERS
Corrected Reflectance (True Color)
Suomi NPP / VIIRS
Corrected Reflectance (True Color)
Aqua / MODIS
Corrected Reflectance (True Color)
Terra / MODIS
+ Add Layers
Start Comparison
200 km
100 mi
1 DAY
2019 NOV 05
SEP 2019
OCT 2019
NOV 2019
DEC 2019
JAN 2020
DAY


WORLDVIEW
2 Layers
Flood product 2-day
200 km
100 mi
22.1221°, 95.2734° EPSG:4326
1 DAY
2019 NOV 06
SEP 2019
OCT 2019
NOV 2019
DEC 2019
JAN 2020
DAY

LANCE: Product changes

- Operating on swath granules vs pre-mosaicked tiles
  - Better cloud-shadow screening on 1-day products
  - Lower latency product delivery (as soon as Aqua data available)
  - 10 x 10 degree product tile updates as new swath granules available
- Adding “recurring flood”
- Adding global generation of 1-day product
- Discontinuing generation of 14-day product
- Distribution format changes
- Distribution website change

Changes in output data values

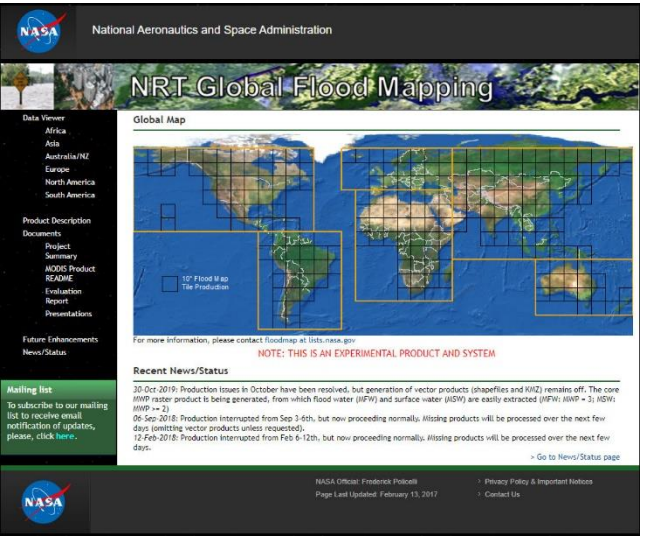
	Pre-LANCE	LANCE
Insufficient data	0	**255**
No water detected	1	**0**
Permanent water	2	**1**
Recurring flood	NA	**2**
Flood	3	**3**

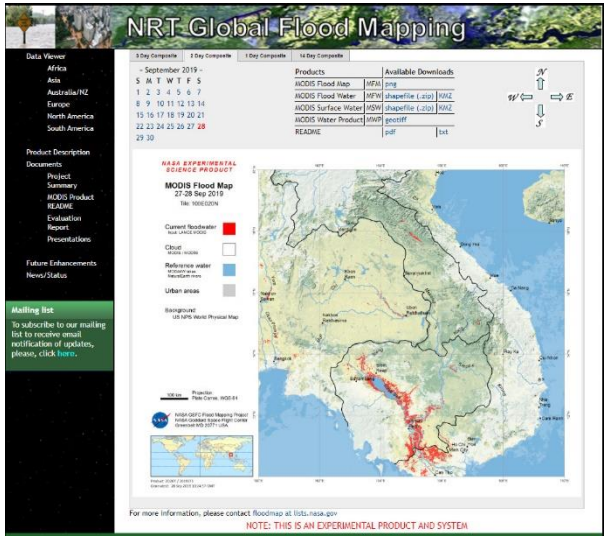
Changes in output format

- Pre-LANCE current product
  - 1 geotiff file for each 1-day, 2-day, and 3-day product (per 10 ° x 10° tile)
  - Previously: shapefile and KMZ (Google Earth) formats
- LANCE product
  - 1 HDF file per tile per day, containing all products (1-day, 2-day, and 3-day)
  - No vector products planned
  - Possibly geotiffs
  - Raw water detections per swath granule available as Level-2 product

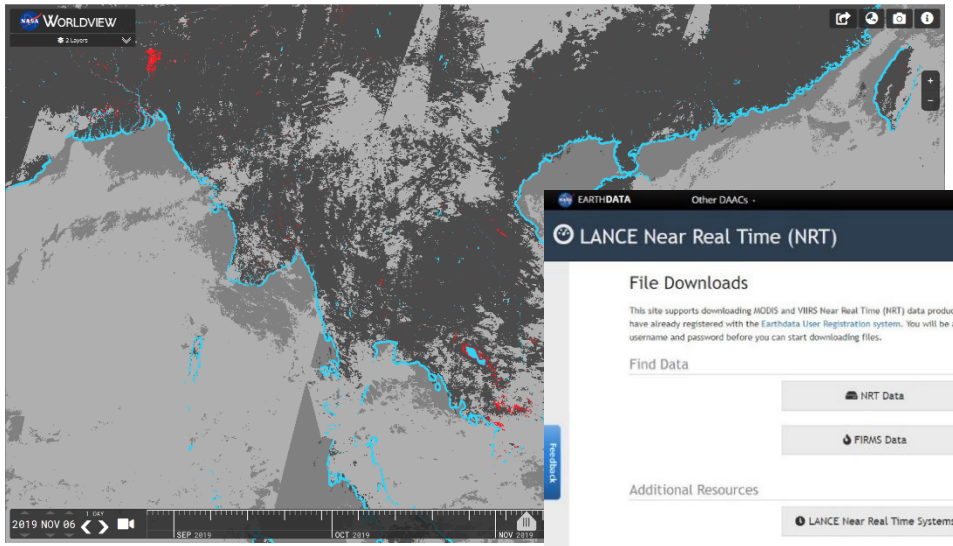
Changes in delivery

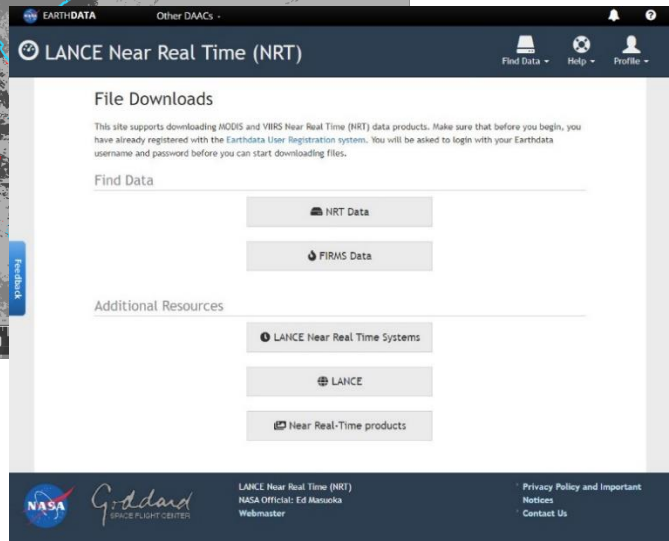
- Pre-LANCE (current)
  - Website with clickable map and reduced-resolution graphic previews
  - No easy method to download many files





- LANCE
  - Worldview browsable map
  - Standard LANCE NRT access: https://nrt3.modaps.eosdis.nasa.gov

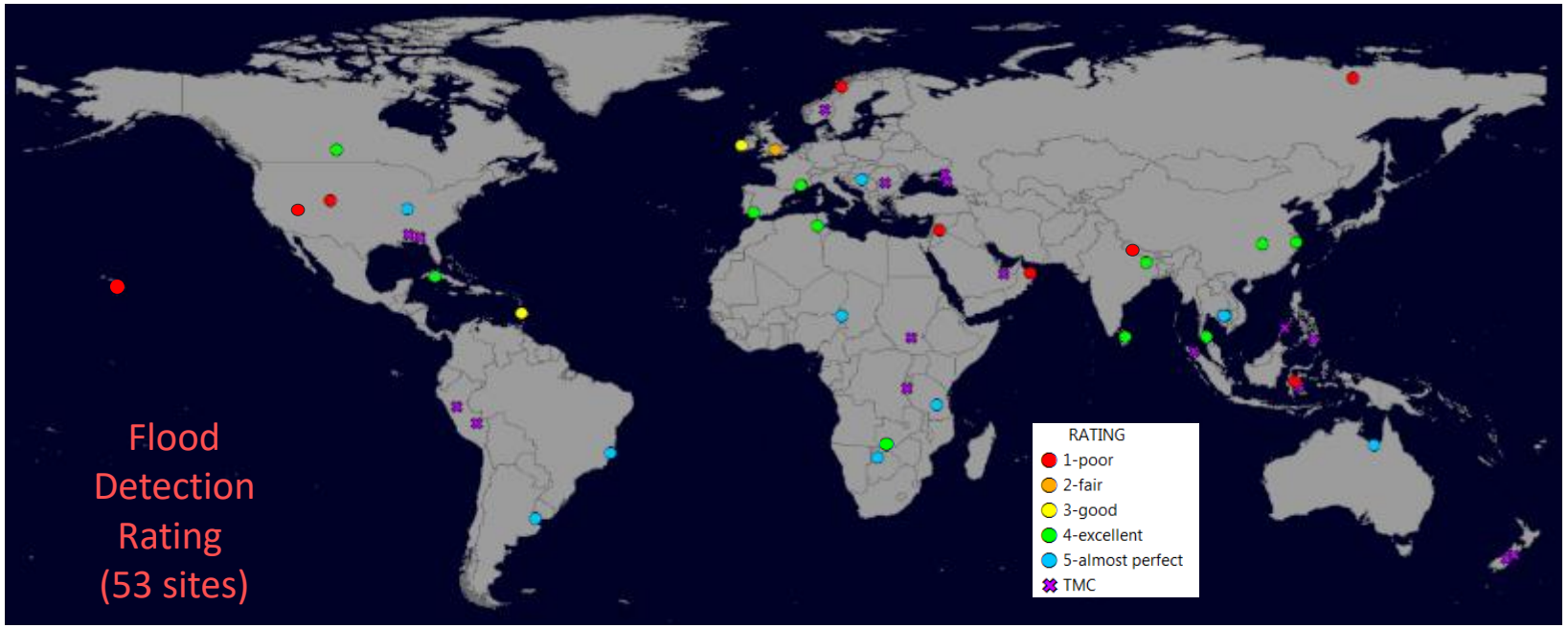


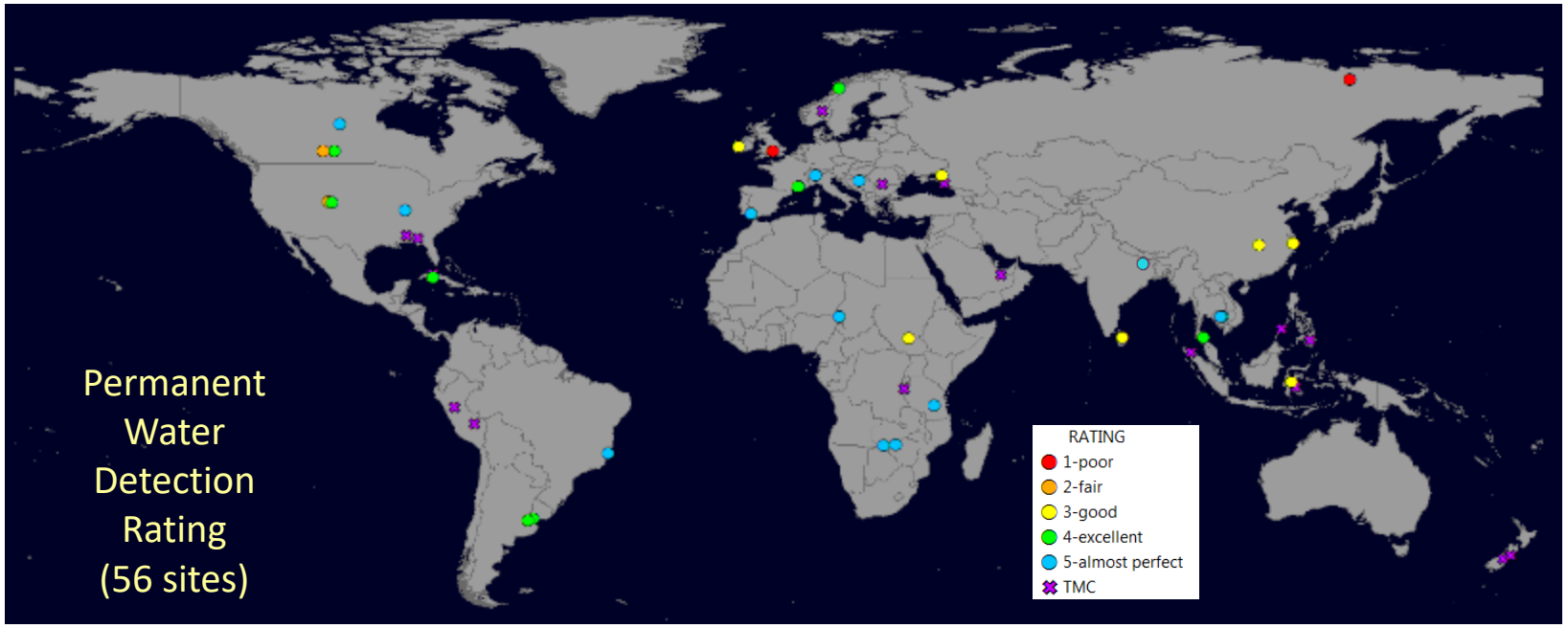


Validation

- Purpose:
  - Is water detection algorithm correctly detecting water that is visibly obvious? Are certain situations problematic?
  - Do we see differences between detection of flood vs normal water?

- Method:
  - Manual qualitative assessment, using raw MODIS or Landsat imagery to inform.
    - Ground truth is difficult to find, expensive to collect, and generally biased towards accessible locations.
  - Flood events selected from DFO master list of recent floods
    - Global distribution.
    - Including areas with high and low cloud cover (humid tropics to arid regions).
    - Varying landcovers.


Flood
Detection
Rating
(53 sites)
RATING
1-poor
2-fair
3-good
4-excellent
5-almost perfect
TMC


Permanent
Water
Detection
Rating
(56 sites)
RATING
1-poor
2-fair
3-good
4-excellent
5-almost perfect
TMC

Flood Detection Ratings

RATING	Count	%
5-almost perfect	11	21
4-excellent	10	19
3-good	2	4
2-fair	1	2
1-poor	11	21
TMC - too many clouds	17	33
TOTAL	53	100

66% of clear

Permanent Water Detection Ratings

RATING	Count	%
5-almost perfect	15	28
4-excellent	9	17
3-good	7	13
2-fair	2	4
1-poor	4	8
TMC - too many clouds	16	30
TOTAL	54	100

84% of clear

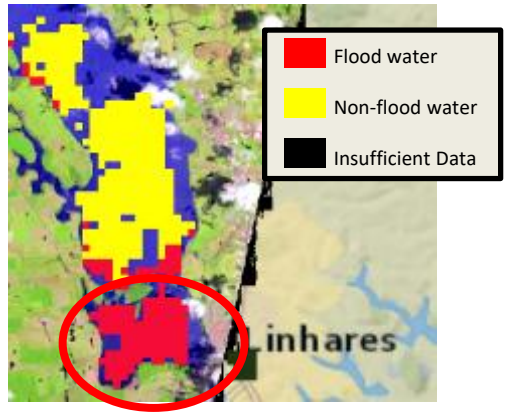
Correct flood and permanent water identification

Brazil: 02 January 2014

Base map

Landsat 8 Pre-flood
Apr 21, 2013

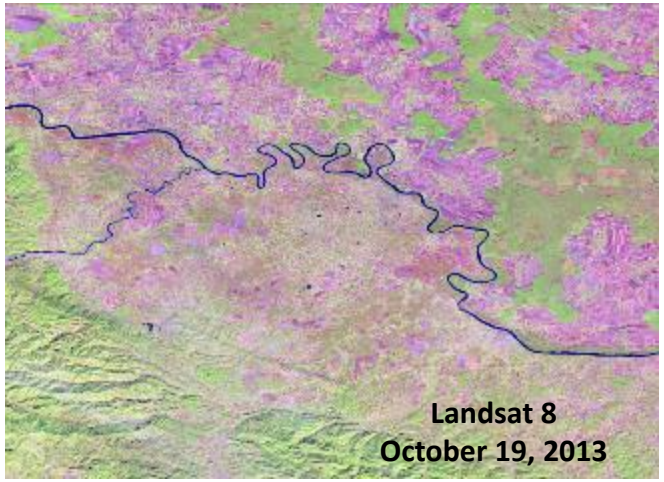
Landsat 8 Flood
Jan 2, 2014

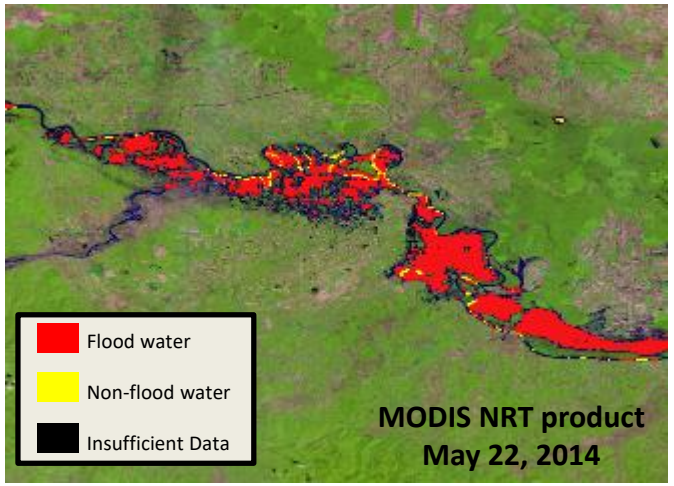


MODIS NRT product
Jan 3, 2014

Correct flood identification

Sava river / Bosnia and Herzegovina:
23 May 2014



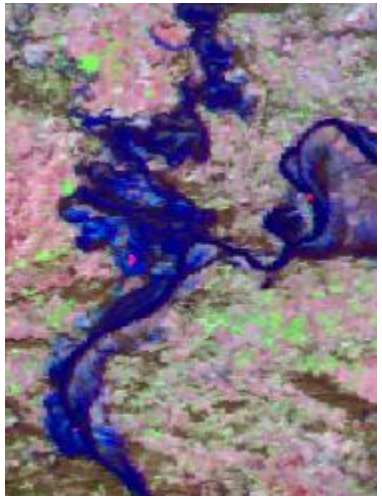


Correct flood identification

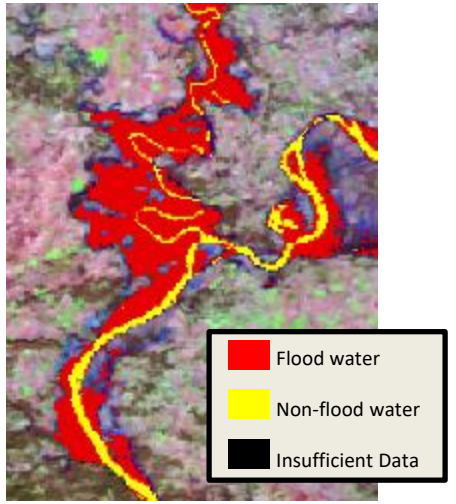
Mississippi (KY/IN/IL):
04 Jan 2014

Base map

MODIS (MOD09) Pre-Flood
Oct 12, 2013



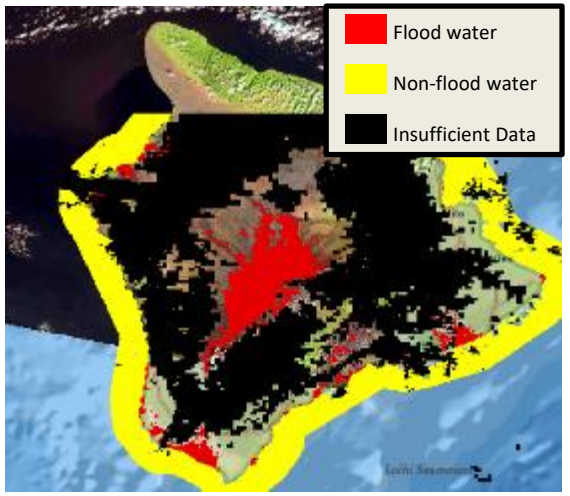
MODIS (MOD09) Flood
Jan 4, 2014



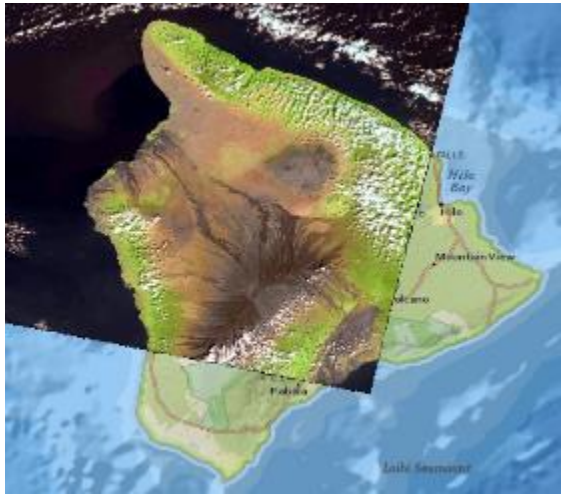
MODIS NRT Product
Jan 4, 2013

Barren rock / volcanic false positives

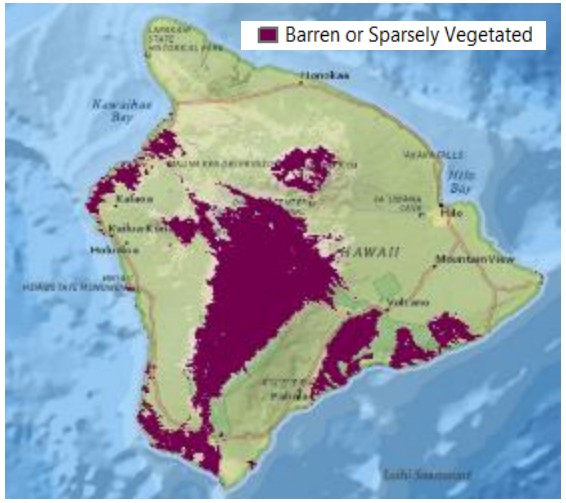
Mauna Loa, **Hawaii:** 17 Dec 2013



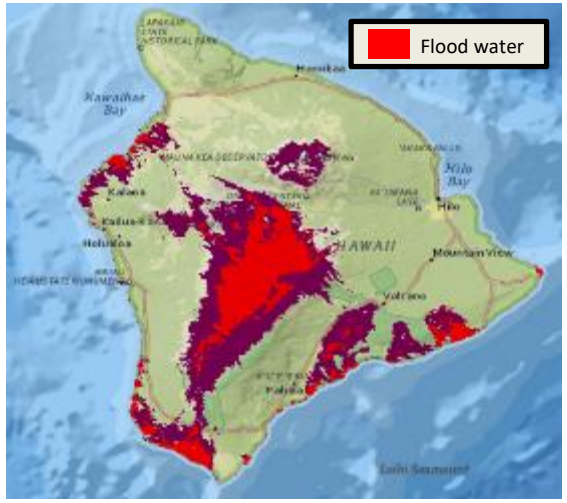
MODIS NRT Product



Landsat 8



MODIS (MCD12Q1) IGBP Land Cover



MODIS IGBP Land Cover with flood water

Flood detection limitations

- Cloudiness
- Flood spatial extent
  - 250 m pixels
- Flood temporal extent
  - Flash floods / short duration on ground
- Landcover
  - Water under tree cover
  - Urban
  - Exposed volcanic rock

Future directions

- Backprocessing archive
  - Nearly 20-year history of large-scale surface water dynamics for much of globe!
- Add VIIRS
  - Only afternoon, but adds additional observations, removes swath gaps
  - Somewhat lower resolution (375 vs 250 m)
  - Will become critical when Aqua fails
- Improve terrain shadow masking
- Alert system

Potential Direct Readout Opportunities

- Use our products, customize for local case
  - Customized permanent and seasonal water layers to identify flood
  - Potentially have staff available to evaluate best product per event, and incorporate local maps and knowledge

- Generate products directly
  - Latency
    - Reduced further with direct broadcast.
  - Customize water detection algorithms
    - Optimize for local conditions / landcover

Thank you!

For more information:

dan.slayback@nasa.gov

SSAI

LANCE

NASA

Hydrology Laboratory
Goddard Space Flight Center

Dartmouth Flood Observatory