TC4 Aqua (Terra) Validation, Science, and Mission Strategy

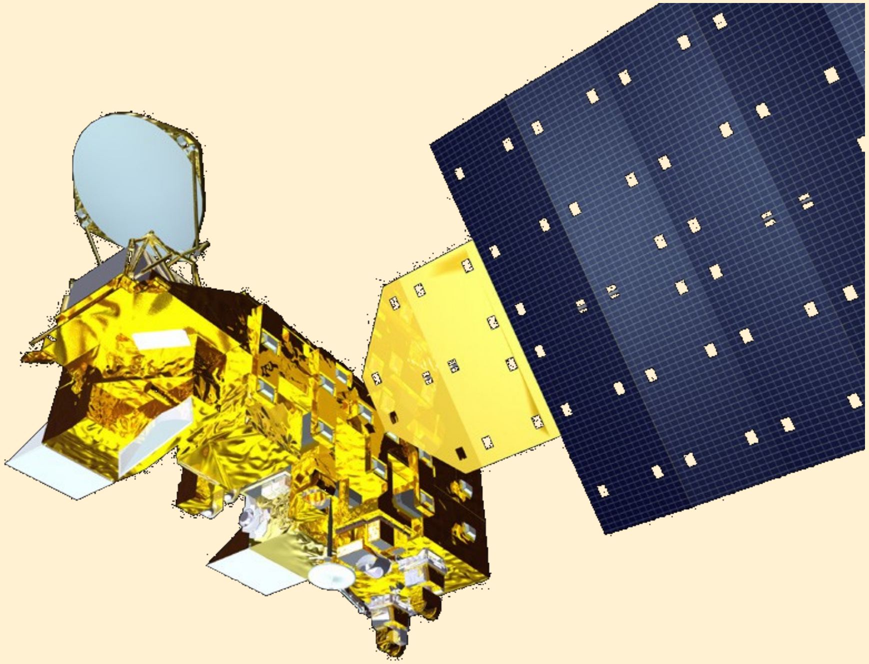
Steve Platnick [1]
&
B. Kahn [2], S. Davis [3], M. D. King [1], P. Pilewskie [3], J. Riedi [4], F. Evans [3], J. Wang [1]

[1] NASA GSFC; [2] JPL; [3] CU; [4] LOA, France

TC4 Science Team Meeting

CSC, Greenbelt MD

26 April 2007



Outline

- Aqua (A-Train, Terra) Overview
  - Instruments
  - Algorithms/retrieval products
- Aqua Validation (MODIS, AIRS examples)
- Aqua Science
- Thoughts on Flight Plans

Aqua Platform

Launch: 4 May 2002 (currently in "Senior Review" process)

Orbit: 705 km, sun synchronous, 1330 LT equatorial crossing (ascending node)

Payload & Teams

AIRS, **AMSU-A**, **HSB** (Brazil): cross-track sounding suite. JPL (M. Chahine). HSB scan motor failure in Feb 2003.

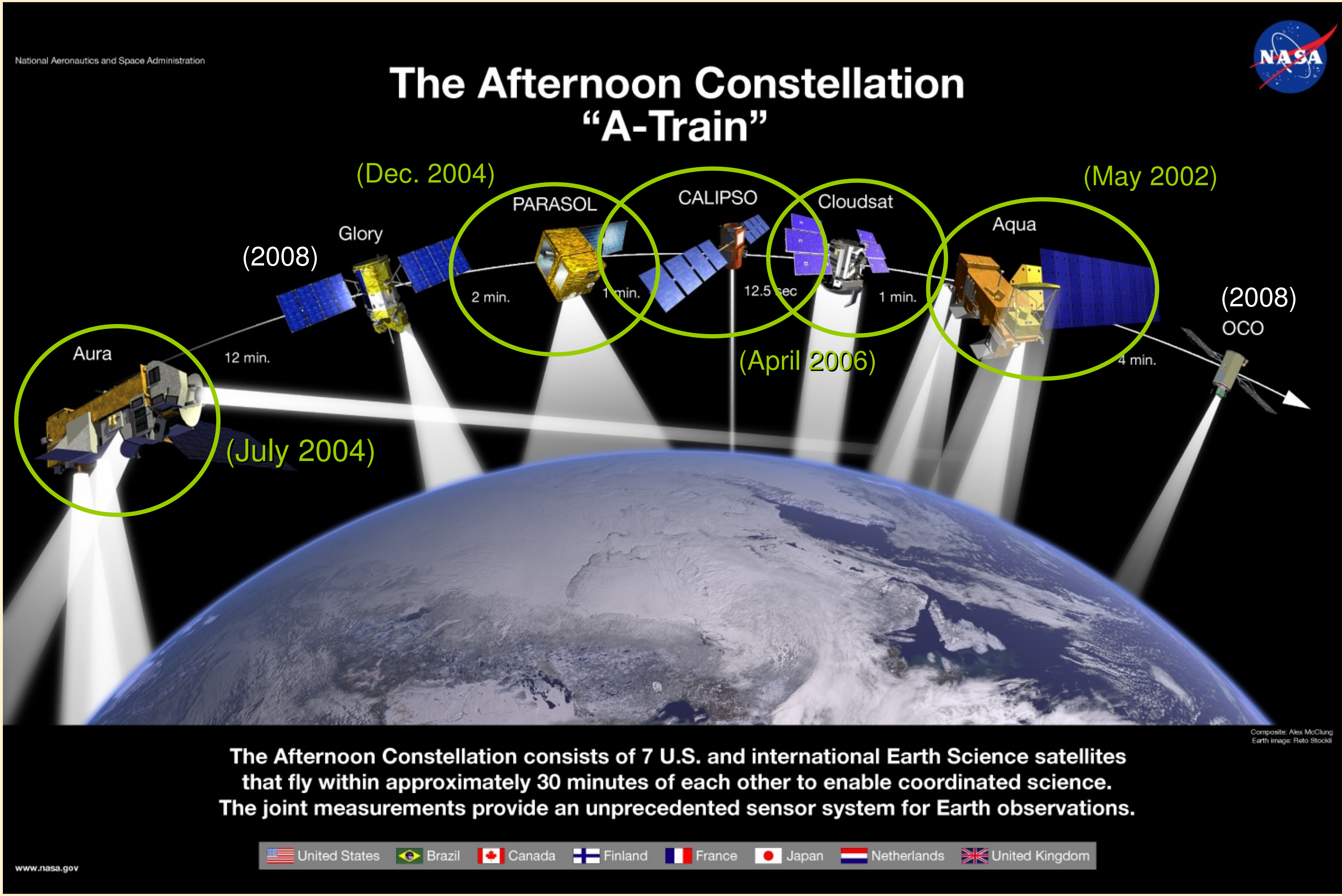
AMSR-E: conical microwave scanner (JAXA), U. Alabama, Huntsville (R. Spencer) & JAXA (A. Shibata)

MODIS: imager, U. Utah (V. Salomonson). Also on Terra.

CERES: radiation budget, NASA LaRC (B. Wielicki). Also on Terra.

General Mission Objectives

Enhance understanding of the global water cycle (vapor, clouds, snow/ice, soil moisture) and other climate system components, improve numerical weather forecasting, allow for diurnal observations (MODIS,CERES on Terra).


National Aeronautics and Space Administration
NASA
The Afternoon Constellation
“A-Train”
(Dec. 2004)
(May 2002)
(2008)
Glory
PARASOL
CALIPSO
Cloudsat
Aqua
2 min.
1 min.
12.5 sec
1 min.
(2008)
OCO
Aura
12 min.
(April 2006)
4 min.
(July 2004)
Composite: Alex McClung
Earth image: Reto Stockli
The Afternoon Constellation consists of 7 U.S. and international Earth Science satellites
that fly within approximately 30 minutes of each other to enable coordinated science.
The joint measurements provide an unprecedented sensor system for Earth observations.
United States
Brazil
Canada
Finland
France
Japan
Netherlands
United Kingdom
www.nasa.gov

The Afternoon Constellation (A-Train)

Matrix of Operational/Standard Level-2 (pixel-level) Cloud Products

	MODIS (&Terra)	AIRS	AMSR -E	CERES (&Terra)	OMI	MLS	POLDER	CPR	CALIOP
cloud detection	X						X	X	X
cloud height/pressure	X	X			X		X	X	X
multilayer info	X						X	X	X
cloud phase	X						X		X
τ	Ξ						Ξ	Ξ *	
ρ_{ε}	Ξ						Ξ	Ξ *	
ΙΩΠ	Ξ					Ξ		Ξ	
ΛΩΠ	Ξ		Ξ					Ξ *	
φλυξ ηεατινγ ρατεσ				Ξ				Ξ *	
	1 km	13	~25	20	~20	~100	6	0.5, 2.5	~ 0.06, 1.0*

2D structure: horizontal

vertical/horizontal

** w/MODIS*

** avg. of 3 shots for BL clouds*

The Afternoon Constellation (A-Train)

Matrix of Operational/Standard Level-2 (pixel-level) Cloud Products

	MODIS (&Terra)	**AIRS**	**AMSR -E**	**CERES** (&Terra)	**OMI**	**MLS**	**POLDER**	**CPR**	**CALIOP**
cloud detection	X						X	X	X
cloud height/pressure	X	X			X		X	X	X
multilayer info								X	X
cloud phase	X						X		X
τ	Ξ						Ξ	Ξ *	
ρ_e	Ξ						Ξ	Ξ *	
ΙΩΠ	Ξ					Ξ		Ξ	
ΛΩΠ	Ξ		Ξ					Ξ *	
φλυξηεατινγ ρατεσ				Ξ				Ξ *	

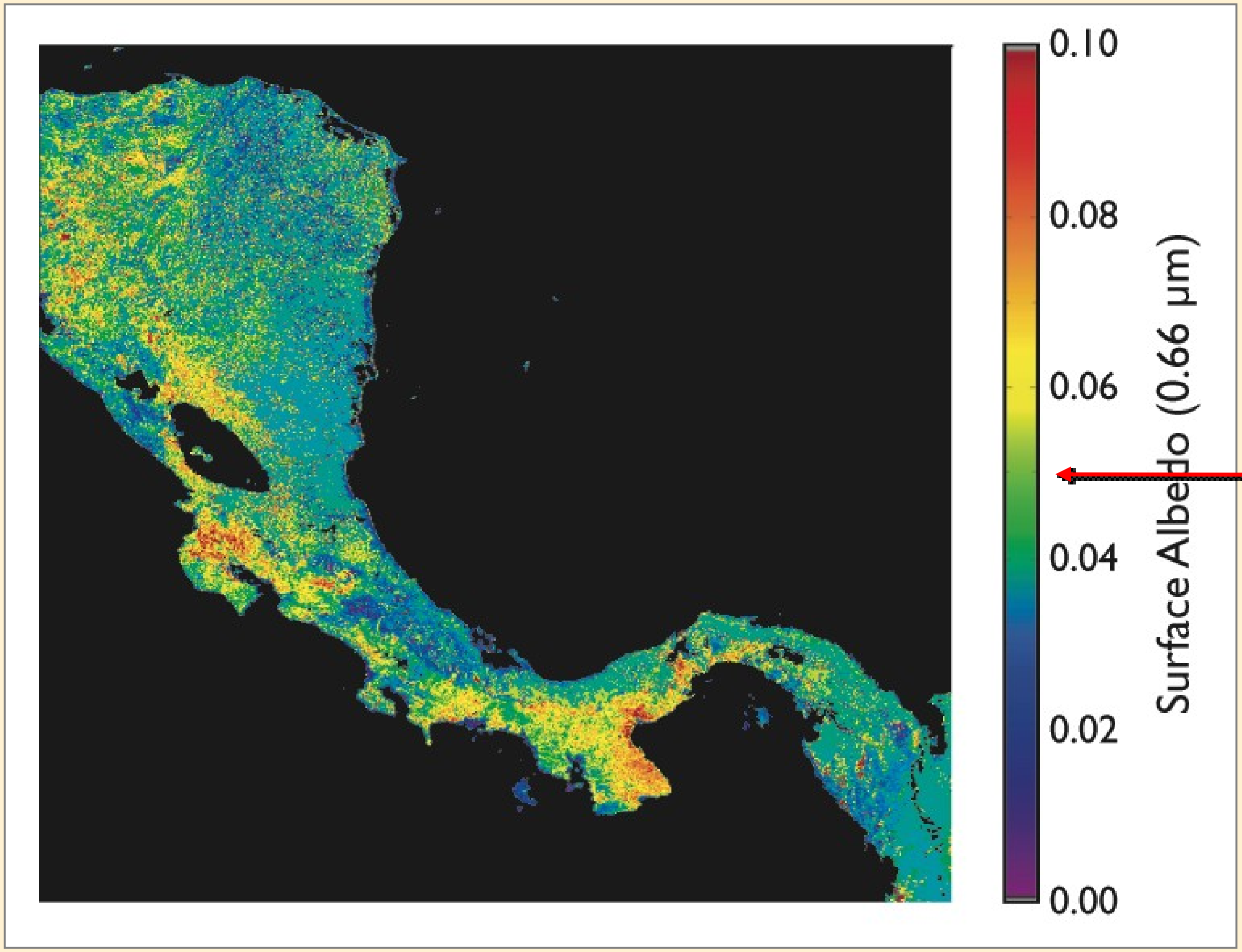
- Requires daytime observations (i.e., ~1330 LT Aqua overpass, MODIS also at 1030 LT w/Terra)
- More robust/enhanced or complete retrievals w/daytime obs

TC4 Aqua Validation Summary

- Aqua ice cloud and related validation needs
  - Instrument characterization, e.g., radiometric validation, etc. (Level 1)
  - Macrophysical retrievals: detection (sun glint discrimination), phase (lack of suitable solar bands for passive methods, mixed phase detection and optical properties), multilayer scene detection capabilities
  - Cloud top "height" retrievals: IR (MODIS, AIRS) vs. O_2 A-band (POLDER), O_2-O_2 (OMI), Raman (OMI), Rayleigh polarization (POLDER)
  - Retrieval of vertically integrated quantities: Ice cloud optical thickness, "mean" effective radius, IWP (MODIS, AIRS)
- What TC4 can contribute
  - Instrument/algorithm simulators: ER-2
  - In situ: ice cloud in situ size/habit distributions for ice model validation, extinction, effective radius, IWC, vertical structure, information on sub-pixel and general 3D cloud inhomogeneity
  - Cloudy atmosphere radiative properties (spectral and integrated fluxes)
  - Surface boundary conditions: land and ocean spectral albedo under diffuse and direct illumination for MODIS (SSFR), land spectral emissivity for AIRS

Central America Surface Albedo at 0.66 µm (diffuse illumination) from MODIS

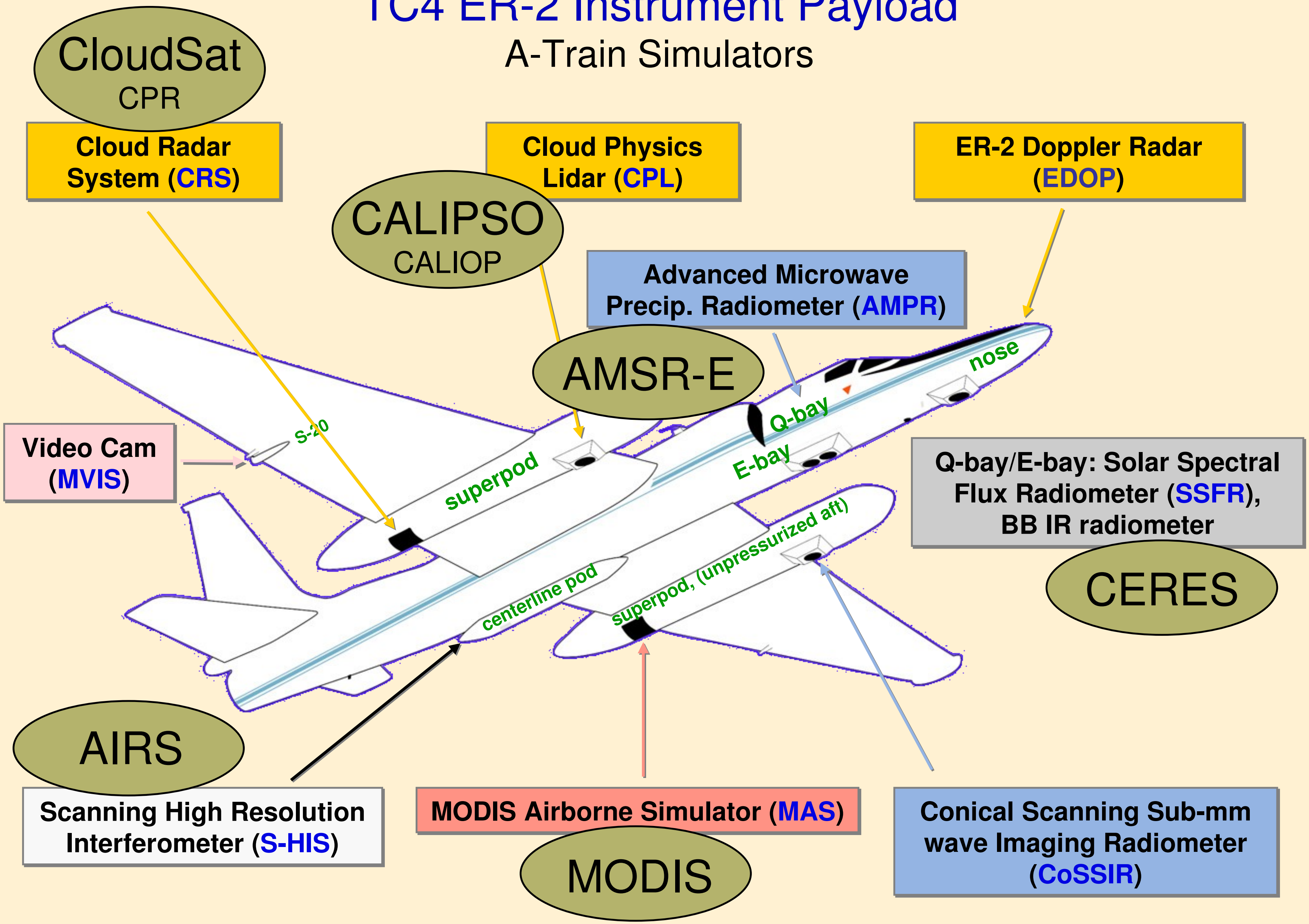
12-27 July 2001, from Moody et al., *TGRS*, 2005



Impacts thin cirrus retrievals: optical thickness of ~0.5 over black surface gives a reflectance of 0.05 at 0.66 µm (r_e=30 µm)

TC4 ER-2 Instrument Payload

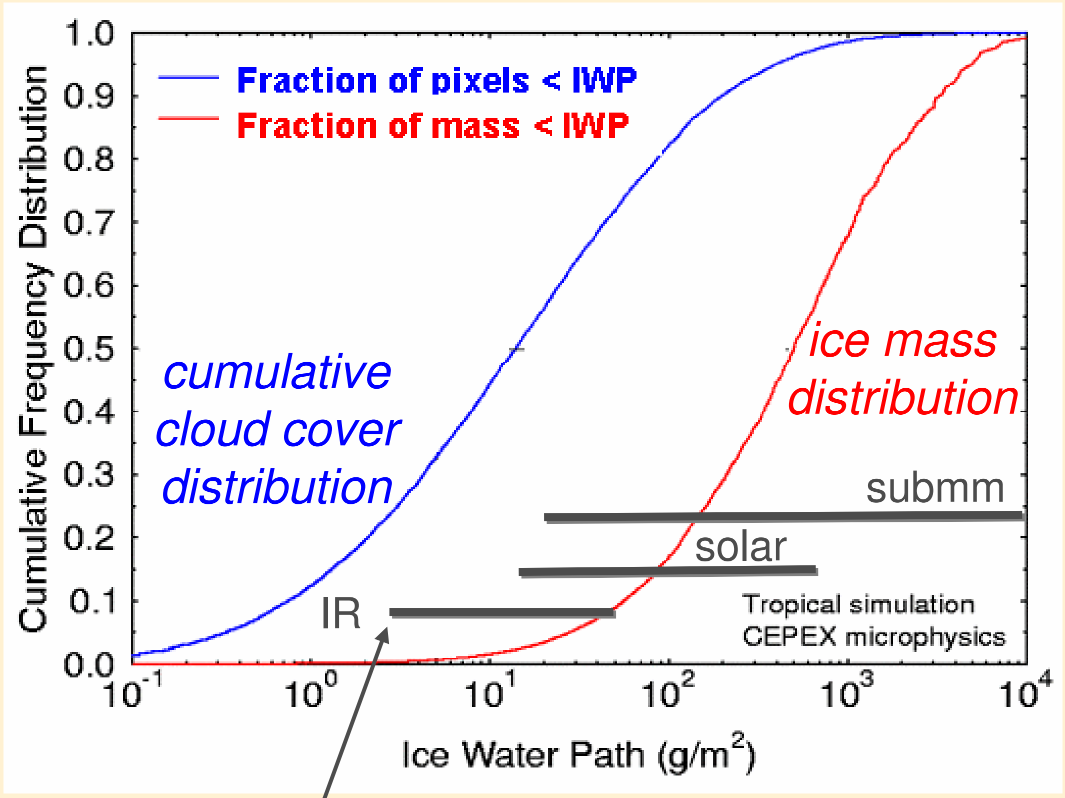
A-Train Simulators



Why Ice Clouds Are Difficult - Dynamic Range

Solar/IR Retrieval Space vs. IWP Distributions

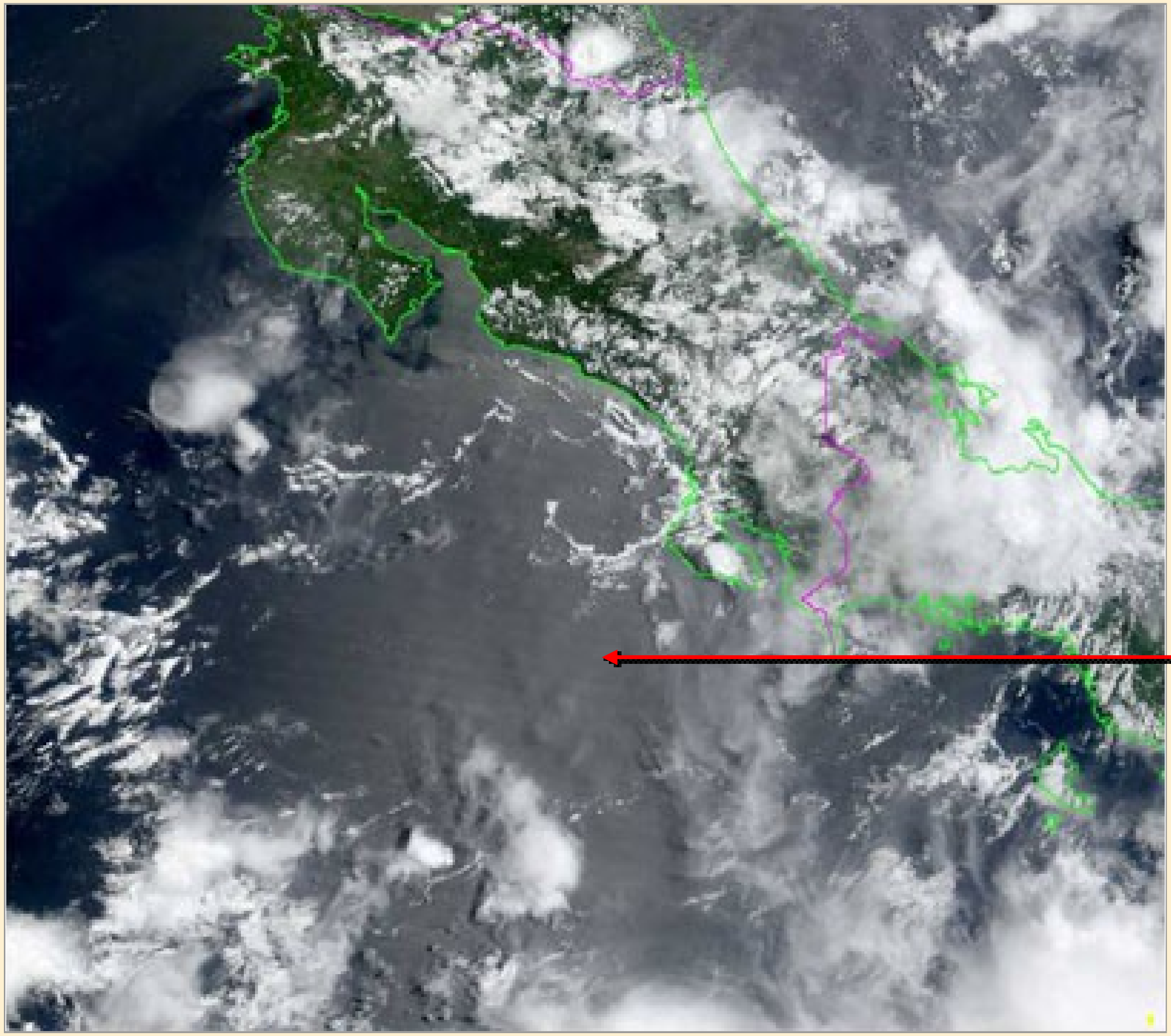
simulations from *Evans et al.*, 2002



~ 50% relative unc. range

Example MODIS Imagery for the TC4 Region

from *loaamma.univ-lille1.fr/modissurvey/*,
L. Gonzalez, C. Deroo, LOA

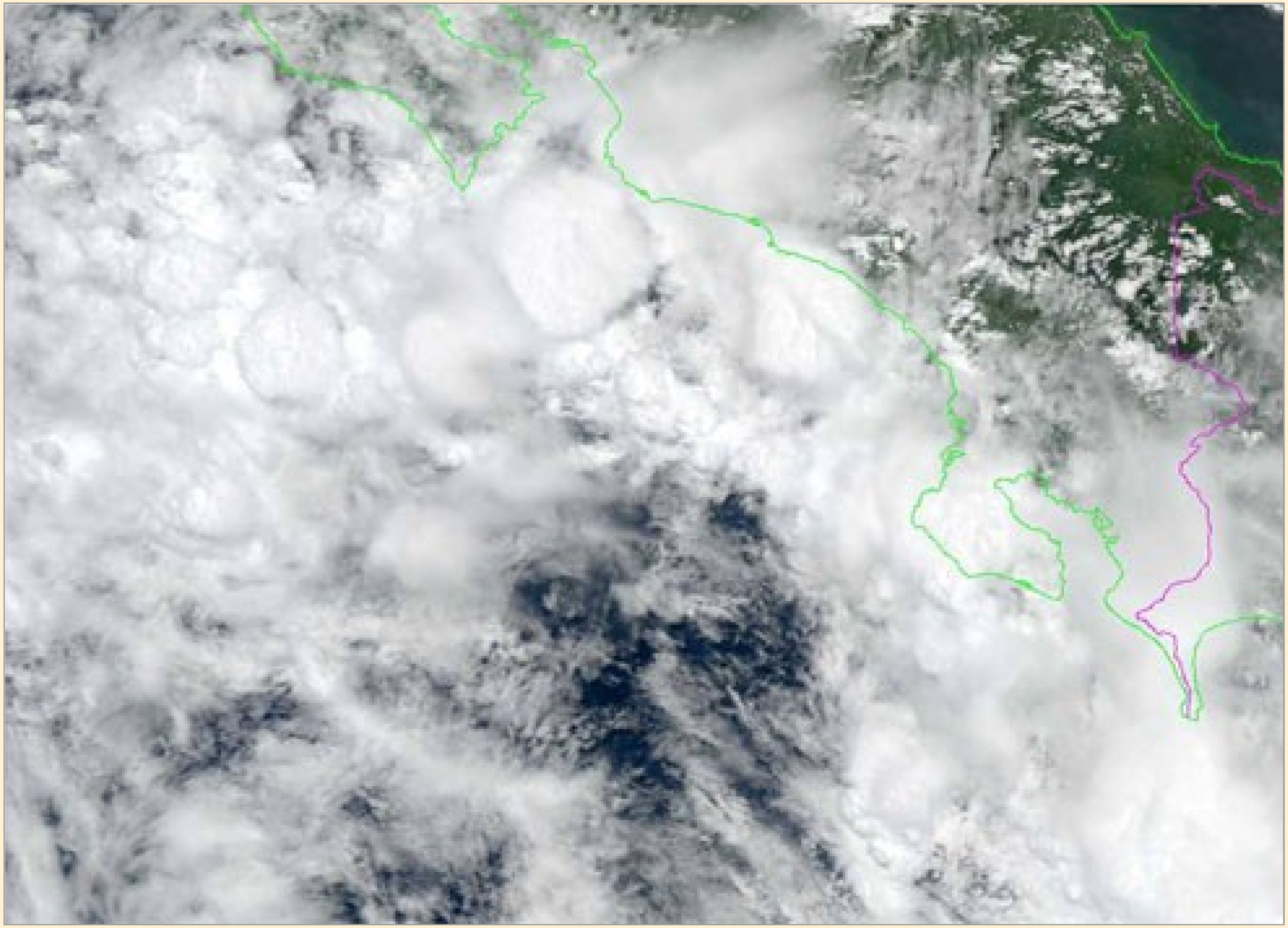


MODIS Terra
8 Aug 2006

sun glint

Example MODIS Imagery for the TC4 Region

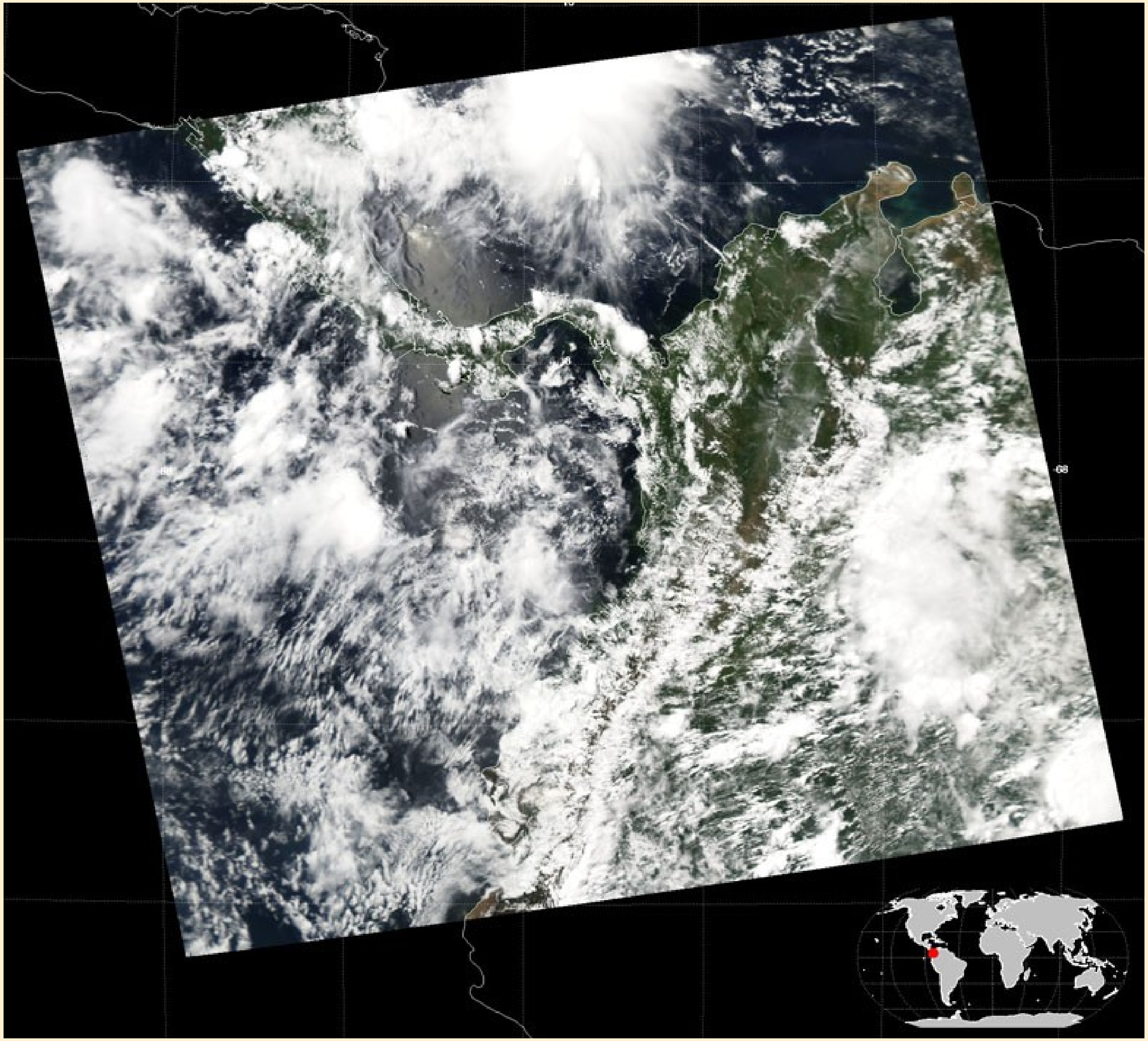
from *loaamma.univ-lille1.fr/modissurvey/*,
L. Gonzalez, C. Deroo, LOA



MODIS Terra
26 July 2006

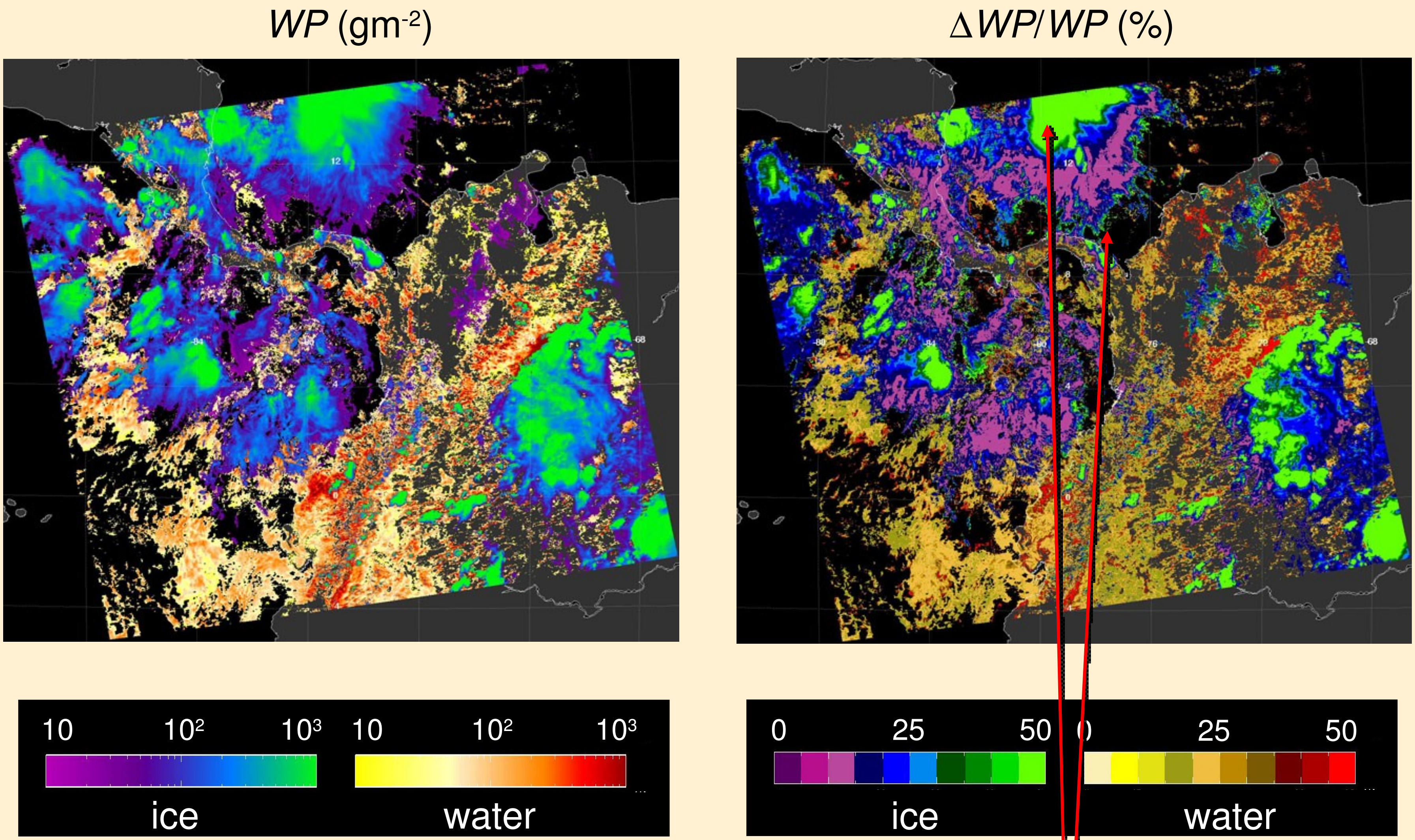
MODIS Aqua IWP Example

20 Aug 2006, Central Am./NW SA, true color composite



MODIS Aqua Example, cont.

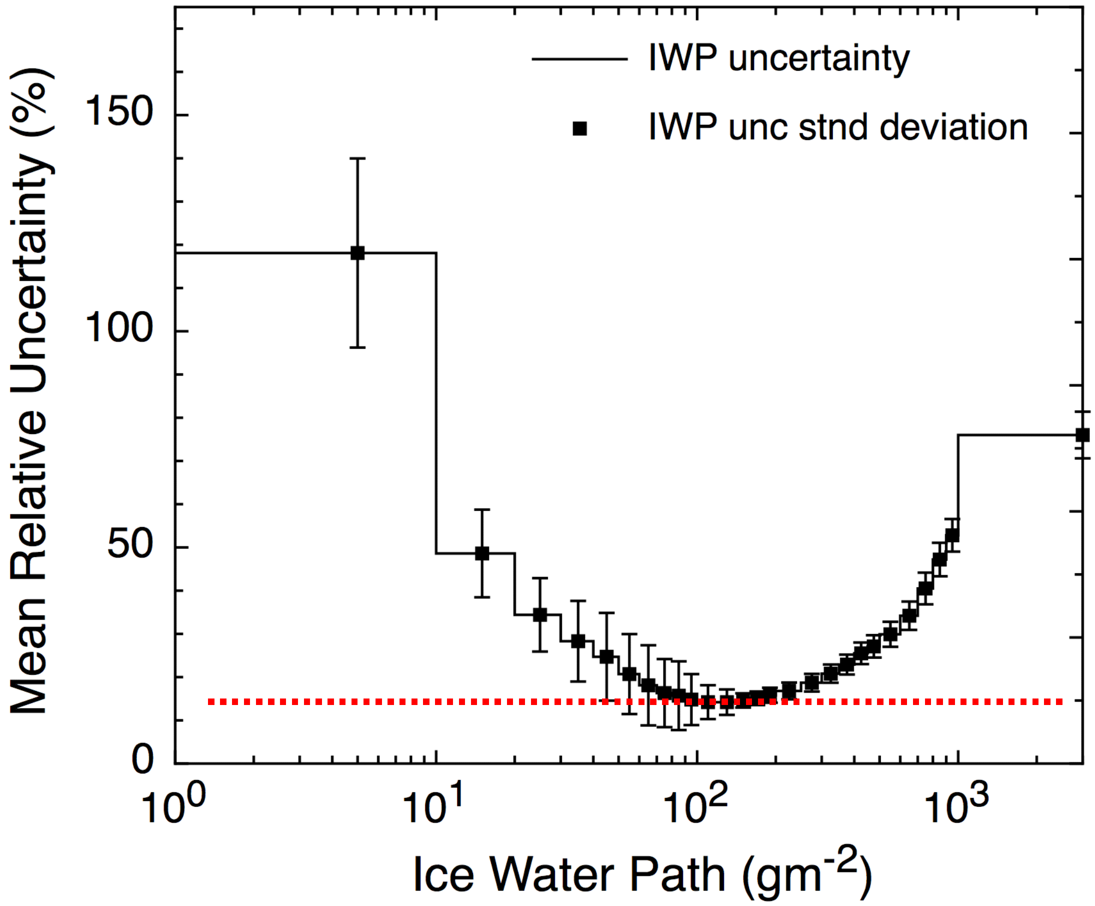
IWP, LWP, and Baseline Uncertainty Estimate



Thinnest & thickest clouds have the greater uncertainty

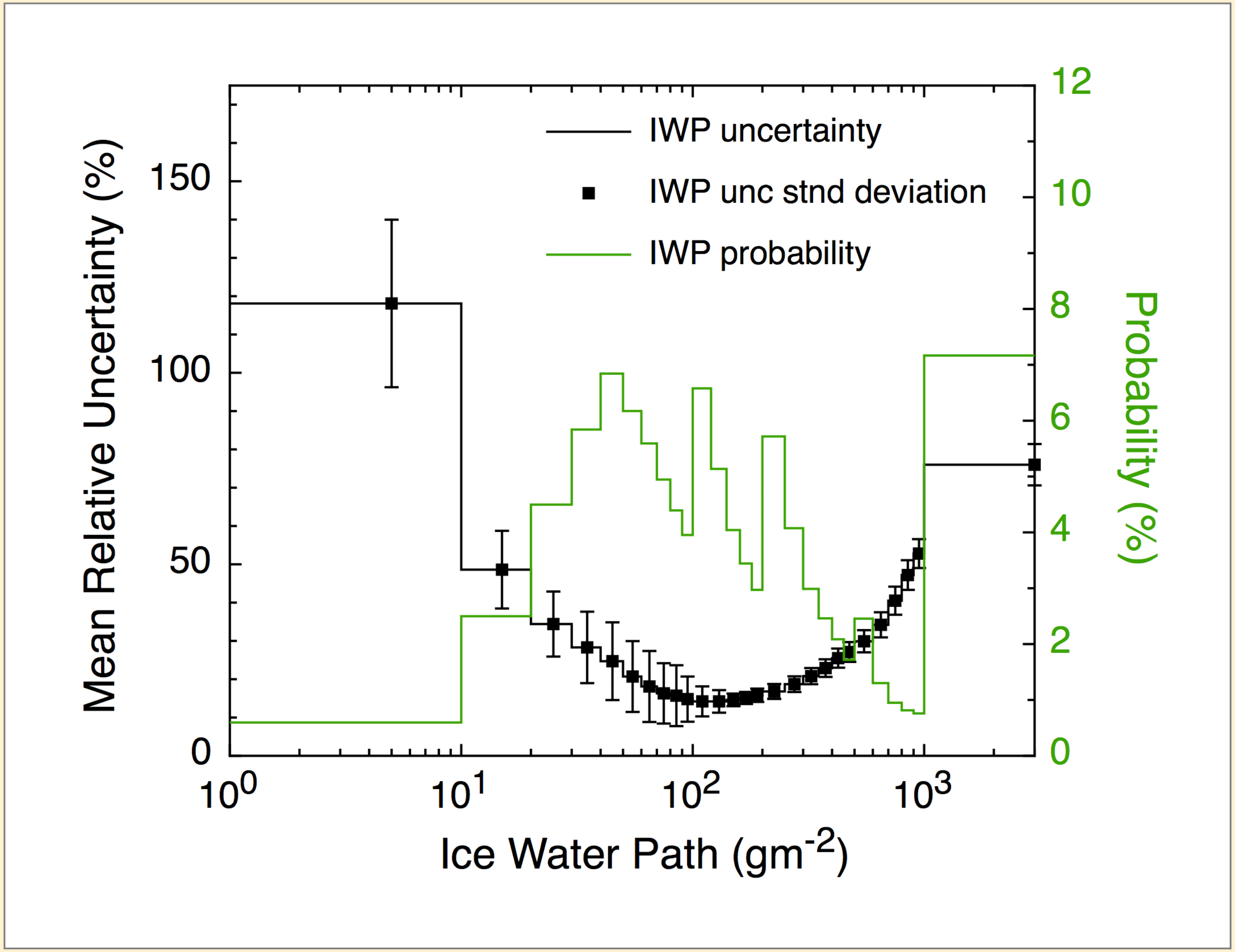
MODIS Aqua Example, cont.

Uncertainty vs. IWP: Ocean Pixels Only



MODIS Aqua Example, cont.

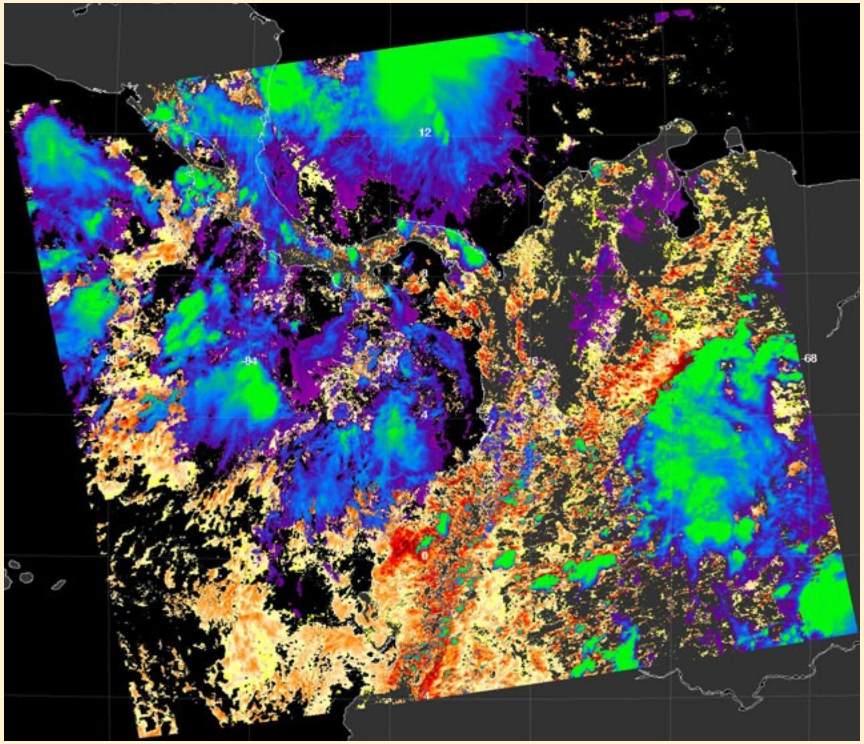
Uncertainty vs. IWP: Ocean Pixels Only



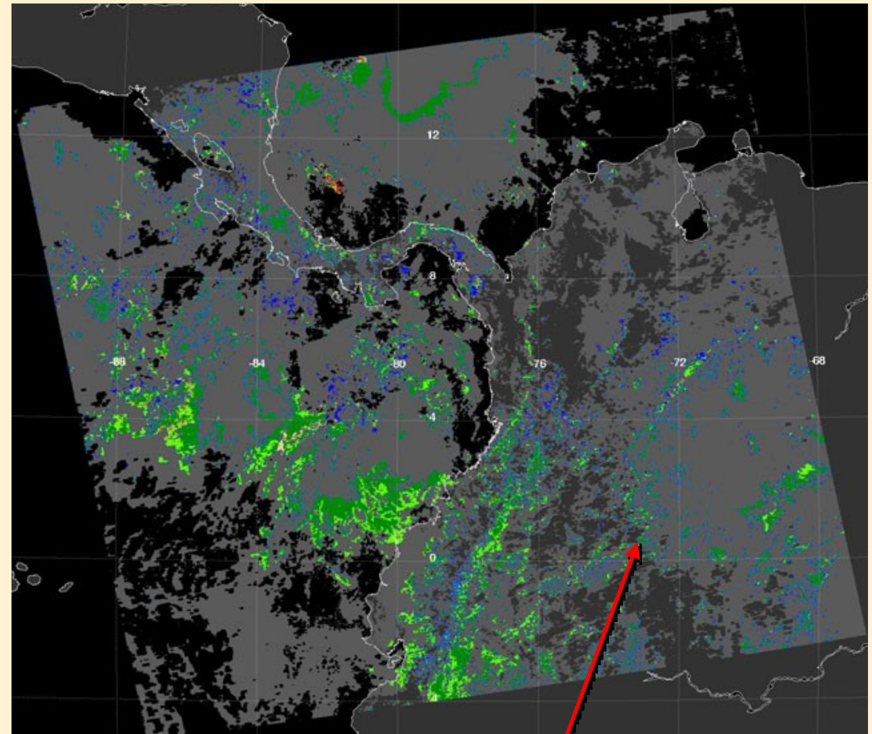
MODIS Aqua Example, cont.

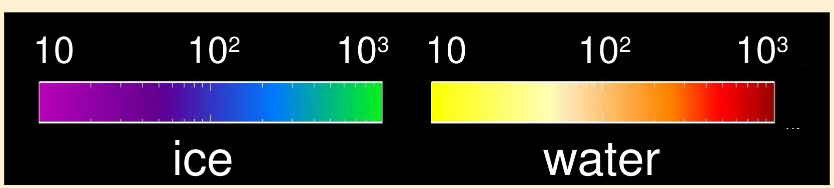
IWP, LWP, and Multilayer Flag

WP (gm^{-2})



Multilayer/phase flag

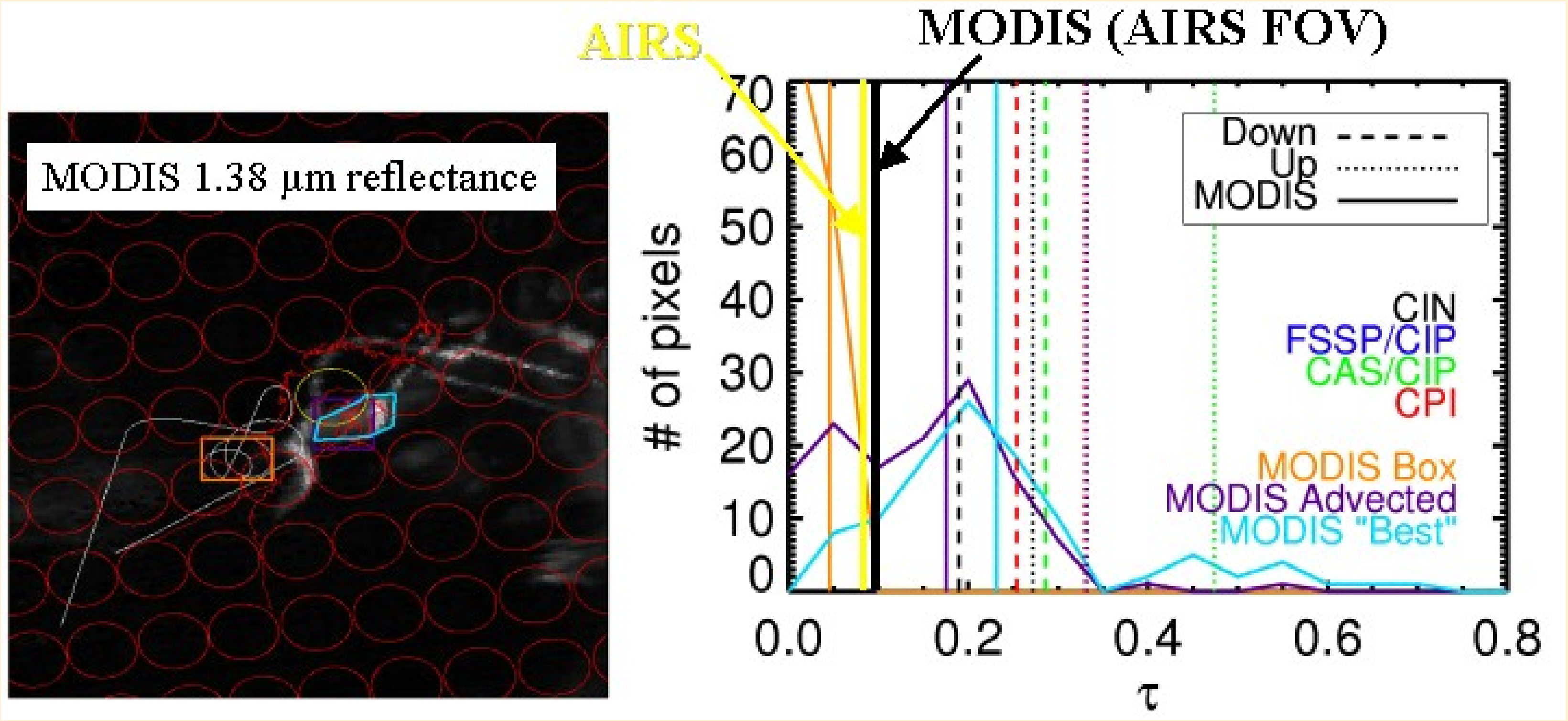




lower-level clouds obscured

AIRS Cirrus Optical Thickness Retrieval Example from MidCIX

Sean Davis and Brian Kahn (JPL)

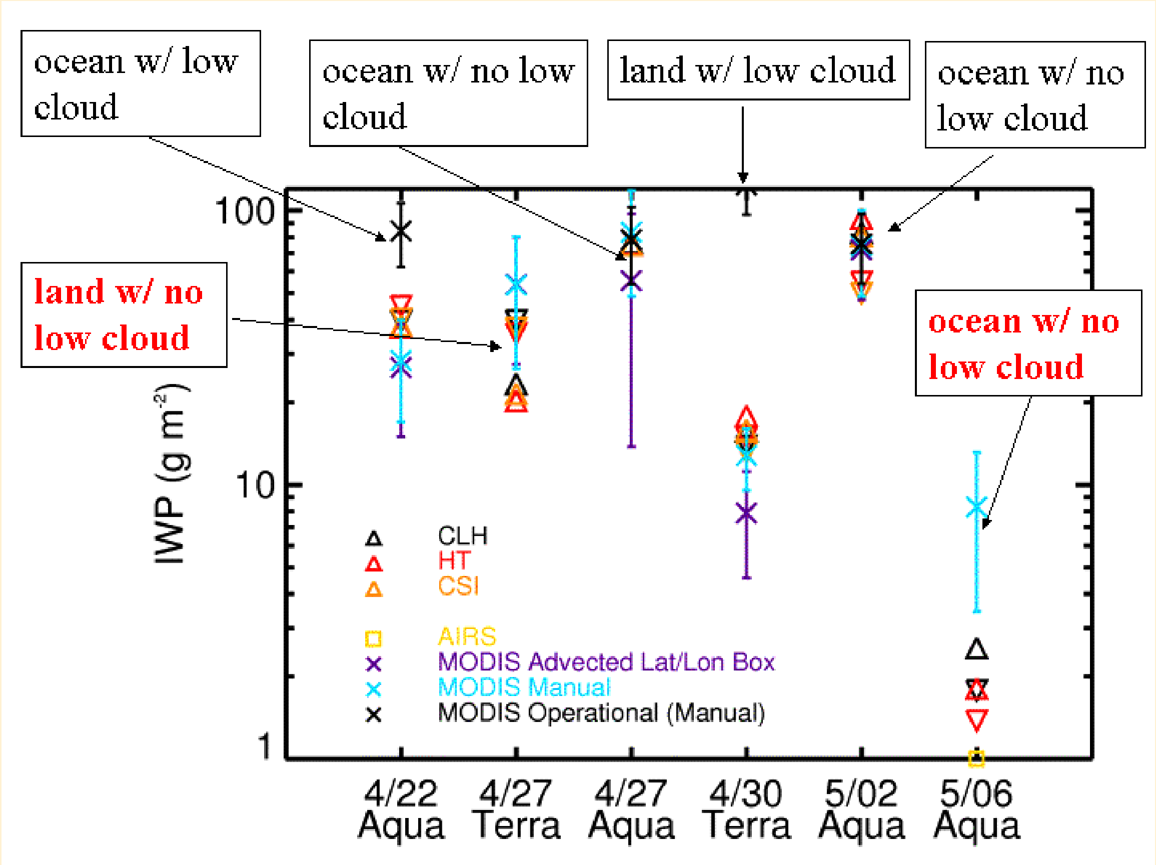


Example coincident measurement during MidCIX 20 min before the Aqua overpass. Note the contrails appear along with thin cirrus clouds.

Davis, Kahn, Avallone, and Meyer, *Eos Trans.*, 2006; Davis et al., *JAOT*, 2007; Yue et al., *JAS*, in press; Zhang et al., *JQSRT*, 2007.

AIRS Cirrus IWP Retrieval Examples from MidCIX

Sean Davis and Brian Kahn (JPL)



IWP for several in situ and satellite retrievals for a set of coincident measurements during the MidCIX campaign.

Other AIRS Validation Interests

- “Cloud Clearing”, i.e., temperature/moisture retrievals in the presence of clouds.
- Cirrus retrieval comparisons in the presence of low clouds.

Relevant Aqua/ER-2 TC4 Science Issues/Questions

<u>Microphysics</u>: MODIS, AIRS, MAS, S-HIS, SSFR

- Evolution of microphysics
  - How does ice particle microphysics change as a function of cloud type/age or lifecycle (i.e., convective core vs. thick anvil vs. thin cirrus)? How do microphysical and other cloud properties (e.g., cloud-top height) depend on core intensity?
  - Are remote observations consistent with previous reports on the existence of large numbers of small particles in cirrus?
- Are ice cloud models used in retrievals (size/habit distributions) appropriate for the TC4 regime?
    - Tropical, midlatitude, polar models? Correlations to dynamic/thermodynamic history?
- *Flight tracks*
  - Multiple ER-2 tracks covering the evolution from core to anvil to thin cirrus. Coincident tracks above (ER-2) and in (WB-57, DC-8) ice clouds.

Relevant Aqua/ER-2 TC4 Science Issues/Questions, cont.

Ice Cloud Raditative Properties: MODIS, CERES, MAS, SSFR, BB IR, models

- How well do radiance-derived ice cloud spectral fluxes compare with direct observations (imager retrievals + BB model vs. observations). How do observed a/c fluxes (SSFR and BB IR) compare with satellite-derived fluxes (CERES).
- *Flight tracks*
  - Coincident tracks above (ER-2) and below (DC-8) ice cloud layers for SSFR and BB IR layer flux measurements.

UT water vapor: AIRS, MODIS, MAS, S-HIS, SSFR, BB IR

- Relationships between UT humidity and the presence/properties of anvils and cirrus?

Validation ???

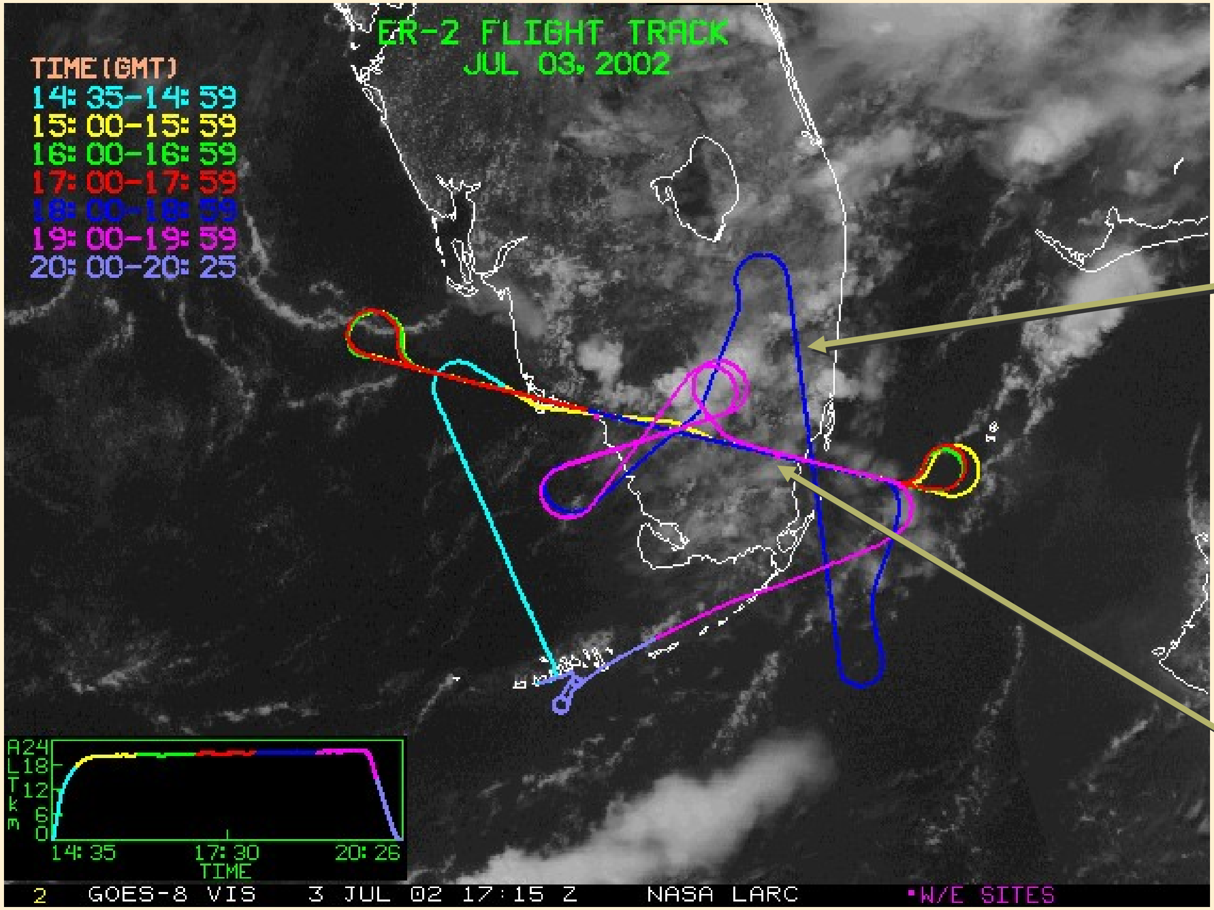
- How can space-based retrievals of quantities known to possess strong variations on small spatial scales (e.g., H_2O, cirrus), be validated in a meaningful fashion? (*lifted from early draft set of TC4 questions by Brian Toon*)
- What do we mean by “validation”?
  - *Understanding and quantifying uncertainties in satellite retrievals* => understanding and quantifying in situ uncertainties is a critical first step (e.g., uncertainty in extinction, cloud water content, etc.)

Thoughts on TC4 Aqua Validation/Science Flight Plans

- Philosophy: “try” to keep it simple, allow more flexible aircraft to make adjustments.
- In situ vertical spirals at satellite overpass for comparison with vertically integrated retrievals
  - B. Kahn: Beware of generating contrails with in situ a/c (MidCIX). Lagrangian and Eulerian spirals useful.
- Multiple aircraft coordination: since exact spatial/temporal coincidence difficult, use flight plans that provide useful statistics (i.e., attempt to sample the same statistical fields) ?!
  - Example: place aircraft in same single repeating track and adjust in real-time as needed. Similar approach as CRYSTAL-FACE.

TC4 Aqua Validation/Science Flight Plan

CRYSTAL-FACE Example, 3 July 2002



Aqua underflight at 1843 UTC

Attempt to capture anvil evolution (and gnd. station overpasses); lower a/c in similar track

http://angler.larc.nasa.gov/crystal/

Summary

- Aqua provides a suite of cloud properties from MODIS, AIRS, and AMSR-E
  - MODIS capability maximized with daytime observations. MODIS daytime imagery and retrievals helpful in interpreting and providing context for AIRS retrievals (cloud fraction within AIRS footprint) as well as in situ data.

- Flight Planning
  - Satellite coordination:

    ER-2 underflights of daytime Aqua/A-Train (1330 LT, nominal) are desirable for retrieval validation. Need a means for assessing the possibility for afternoon coordination. ER-2 underflights of Terra MODIS (1030 LT) also desirable.

    ER-2 underflights of Aqua/Terra require same track orientation (MAS) but exact sub-satellite track not needed (can offset Aqua track by ~200 km to the west to match CloudSat/CALIPSO when feasible).

    DC-8 in situ coordination with Aqua and Terra desirable even if ER-2 (and WB-57) not available. Vertical spirals at overpass desirable for comparison with vertically integrated cloud retrievals.

  - ER-2/DC-8/WB-57 coordination:

    Repeating tracks in attempt to sample similar statistics.

Extras

TC4 Aqua Validation Summary, cont.

- Advantage of near-coincident ER-2 observations
  - Higher spatial resolution retrievals (examination of subpixel and horizontal inhomoeneity effects)
  - Active retrievals away from CloudSat/CALIPSO track
  - Observations not directly available from Aqua: CoSSIR (*IWP*, D_{me}), SSFR and BB IR (DC-8 also)
  - Allow for independent retrieval methodologies and consistency checks (e.g., SSFR, IR sanity checks)

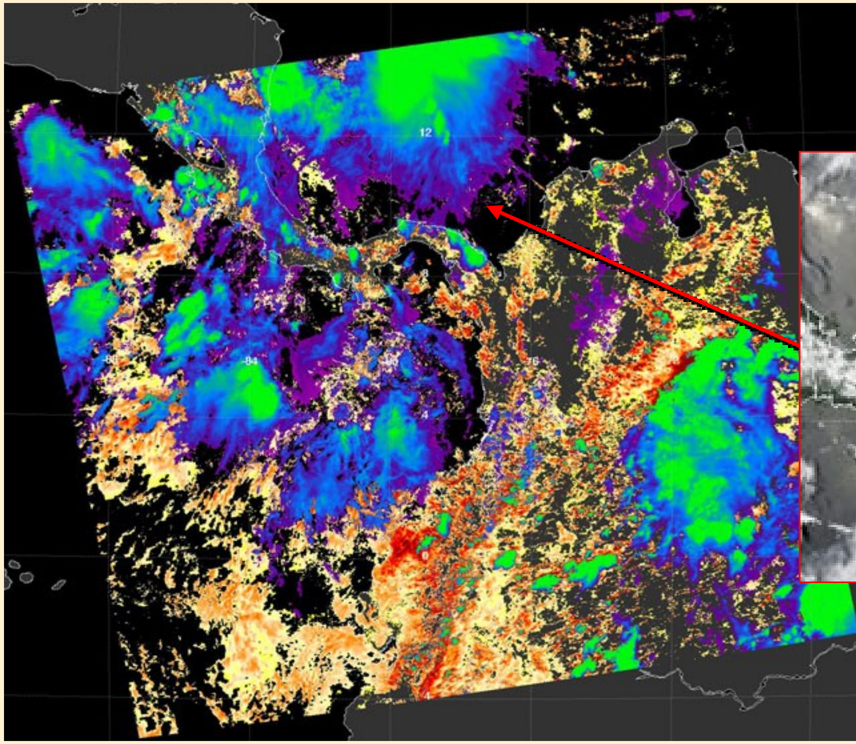
ER-2 Retrieval Summary (standard set)

	MAS	S-HIS	AMPR	SSFR, IR BB	CoSSIR	EDOP	CRS	CPL
cloud detection	X						X	X
cloud height/pressure	X	X					X	X
multilayer info						X	X	X
cloud phase	X	X						X
τ	Ξ	Ξ		Ξ				Ξ
ρ_ε	Ξ	Ξ		Ξ				
$\Delta_{\mu\varepsilon}$					Ξ			
ΙΩΠ	Ξ	Ξ			Ξ		Ξ	
ΛΩΠ	Ξ		Ξ					
φλυξηεατινγ ρατεσ				Ξ				
πρεχιπ.			Ξ			Ξ		
ϖ						Ξ	Ξ	
Τ(ζ)		Ξ						
$H_2O(\zeta)$		Ξ			Ξ			

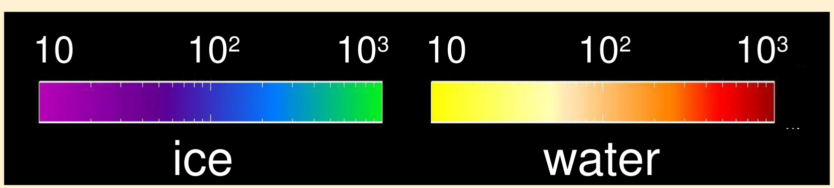
MODIS Aqua Example, cont.

IWP, LWP

WP (gm^{-2})



Missing thin cirrus (failed re retrieval), can be brought back by tweaking surface albedo and phase retrieval



TC4 Aqua/Terra Validation

Generic Remote Sensing Cloud Validation Issues

- If validation means *understanding and quantifying uncertainties in satellite retrievals* … then understanding and quantifying in situ uncertainties is a critical first step (e.g., uncertainty in extinction, cloud water content, etc.)
- Spatial and temporal sampling
  - Exact spatial/temporal coincidence difficult (different a/c speeds, 3D fields, etc.). How to achieve useful temporal/spatial statistics?
- Some basic retrieval products are ill-defined
  - cloud masking (spectral and geometric dependence), cloud-top (in the eye of the beholder) thermodynamic phase (multilayer/phase scenes), local quantities (effective radius is at best a vector, not a scalar)