CERES Ed4 Cloud Properties

P. Minnis, D. Doelling (calibration), W. L. Smith (offline val)

NASA Langley Research Center, Hampton, VA, USA

S. Sun-Mack (QB), Q. Trepte (mask), F-L. Chang (CO2, ML), T. Chee (web, DM), R. Arduini (RTM), K. Bedka (OT tops), S. Bedka (SIST), R. Brown (QC), Y. Chen (clr props, test runs), S. Gibson (graphics), E. Heckert (web, IG), G. Hong (night tau), M. Khaiyer (val), R. Palikonda (offline testing), R. Smith (web, NPP), D. Spangenberg (polar), Y. Yi (thickness), C. Yost (phase)

SSAI, Hampton, VA, USA

P. W. Heck (retrieval algo)

CIMSS, U. Wisconsin, Madison, Wi, USA

P. Yang, Y. Xie (ice cloud models)

Texas A&M Univ., College Station, TX, USA

CERES Science Team Meeting, Livermore, CA, October 4-6, 2011

CERES Cloud Properties

- CERES cloud parameters constitute an independent climate product (CDR)
  - different from the MODIS team products
    - *different algorithms, channels used, input, droplet/ice models, etc.*
    - *different philosophy, CERES wants a value for every cloudy pixel*
      - CC(CERES) < CC(MODIS)

        CCR(CERES) > CC(MODIS) =>
        - *e.g., MODIS cloud optical depth does not represent mean for all cloudy pixels (overestimate)*
      - other properties differ (e.g., Waliser et al., 2009)
  - except of cloud cover, CERES mean values are near center of GEWEX intercomparison
    - *only method to realistically estimate marine StCu heights*
  - matched with radiation data

CERES Cloud Properties

- CERES clouds suffer from same problems as other methods
  - how do we interpret radiances from a real scene using idealized input, models, etc.
  - numerous validation studies have been performed

- CERES algorithms being applied to numerous datasets
  - AVHRR cloud climatology being developed
    - *Kato will make CERES-like ERBE product*
  - ARM satellite cloud products
  - LaRC near-real time analyses of GEOSat data => 30 min – 3-hr data for global and regional domains
    - being assimilated in RUC and Rapis Refresh NWP models
    - being tested for GMAO models

Update of CERES Cloud-related Papers, etc.

Edition-2 related

Zheng, X., B. Albrecht, H. Jonson, D. Khelif, G. Feingold, P. Minnis, K. Ayers, S. Donaher, D. Rossiter, J. Ruiz-Plancarte, and S. Sun-Mack, 2011: Observations of the boundary layer, cloud, and aerosol variability in the southeast Pacific coastal marine stratocumulus during VOCALS-Rex. *Atmos. Chem. Phys.*, **11**, 9943-9959.

Minnis, P., S. Sun-Mack, D. F. Young, P. W. Heck, D. P. Garber, Y. Chen, D. A. Spangenberg, R. F. Arduini, Q. Z. Trepte, W. L. Smith, Jr., J. K. Ayers, S. C. Gibson, W. F. Miller, V. Chakrapani, Y. Takano, K.-N. Liou, Y. Xie, and P. Yang, 2011: CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part I: Algorithms. *IEEE Trans. Geosci. Remote Sens.*, **11**, doi: 10.1109/TGRS.2011.2144601.

(http://www-pm.larc.nasa.gov/ceres/pub/journals/Minnis.CERES.Part.Io.pdf)

Minnis, P., S. Sun-Mack, Y. Chen, M. M. Khaiyer, Y. Yi, J. K. Ayers, R. R. Brown, X. Dong, S. C. Gibson, P. W. Heck, B. Lin, M. L. Nordeen, L. Nguyen, R. Palikonda, W. L. Smith, Jr., D. A. Spangenberg, Q. Z. Trepte, and B. Xi, 2011: CERES Edition-2 cloud property retrievals using TRMM VIRS and Terra and Aqua MODIS data, Part II: Examples of average results and comparisons with other data. *IEEE Trans. Geosci. Remote Sens.*, **11**, doi: 10.1109/TGRS.2011.2144602.

(http://www-pm.larc.nasa.gov/ceres/pub/journals/Minnis.CERES.part.IIo.pdf)

Update of CERES Cloud-related Papers, etc.

Edition-2 related

Yan, H., J. Huang, P. Minnis, T. Wang, and J. Bi, 2011: Comparison of CERES surface radiation fluxes with surface observations over the Loess Plateau. *Remote. Sens. Environ.*, **115**, 1489-1500, doi:10.1016/j.rse.2011.02.008.

Li, J. Y. Yi, P. Minnis, J. Huang, H. Yan, Y. Ma, W. Wang, and J. K. Ayers, 2011: Radiative effect differences between multi-layered and single-layer clouds derived from CERES, CALIPSO, and CloudSat data. *J. Quant. Spectrosc. Radiat. Transfer*., **112**, 361-375.

Smith, G. L., K. J. Priestley, N. G. Loeb, B. A. Wielicki, T. P. Charlock, P. Minnis, D. R. Doelling, and D. A. Rutan, 2011: Clouds and the Earth's Radiant Energy System (CERES), a review: past, present, and future. *Adv. Space Res.*, **48**, 254-263, doi:10.1016/j.asr. 2011.03.009.

Yan, H., J. Huang, P. Minnis, T. Wang, T. Zhou, J. Bi, and B. Zhang, 2011: Comparison CERES surface radiation fluxes and cloud microphysical properties with surface observations over Loess Plateau. *Intl. Symp. Atmos. Light Scattering & Remote Sens. (ISALSaRS'11)*, Lanzhou, China, June 20-24.

Update of CERES Cloud-related Papers, etc.

Edition-4 related

Xie, Y., P. Yang, G. W. Kattawar, P. Minnis, Y. Hu, and D. Wu, 2011: Determination of ice cloud models using MODIS and MISR data. *Intl. J. Remote Sens.*, in press.

Kato, S., F. G. Rose, S. Sun-Mack, W. F. Miller, Y. Chen, D. A. Rutan, G. L. Stephens, N. G. Loeb, P. Minnis, B. A. Wielicki, D. M. Winker, T. P. Charlock, P. W. Stackhouse, K.-M. Xu, and W. Collins, 2011: Computation of top-of-atmosphere and surface irradiances with CALIPSO, CloudSat, and MODIS-derived cloud and aerosol properties. *J. Geophys. Res*., in press.

Sun-Mack, S., P. Minnis, S. Kato, Y. Chen, Y. Yi, S. Gibson, P. Heck, D. Winker, and K. Ayers, 2010: Enhanced cloud algorithm from collocated CALIPSO, CloudSat and MODIS global boundary layer lapse rate studies. *Proc. IEEE 2010 Intl. Geosci. and Remote Sens. Symp.*, Honolulu, HI, July 25-30, DVD-ROM, pp. 201-204.

Chang, F.-L., P. Minnis, R. Palikonda, and S. Sun-Mack, 2011: Retrieving multilayered cloud properties from the SEVIRI and MODIS data. *2011 EUMETSAT Meteorol. Sat. Conf., Oslo, Norway, Sept. 5 – 9.*

Minnis, P. S. Sun-Mack, R. Palikonda, Q. Z. Trepte, Y. Chen, R. F. Arduini, X. Dong, B. Xi, and K. Giannechi, 2011: Retrieving cloud optical properties over snow and ice covered surfaces. *2011 EUMETSAT Meteorol. Sat. Conf., Oslo, Norway, Sept. 5 – 9.*

Sun-Mack, S., P. Minnis, F. –L. Chang, Y. Chen, P. W. Heck, Y. Yi, R. Arduini, Q. Trepte, S. Gibson, R. Smith, R. Brown, and E. Heckert, 2011: CERES Edition 4 cloud properties. *2011 EUMETSAT Meteorol. Sat. Conf., Oslo, Norway, Sept. 5 – 9.*

Chen, Y., S. Sun-Mack, R. F. Arduini, and P. Minnis, 2011: Clear-sky narrowband albedo datasets derived from MODIS data. *Intl. Symp. Atmos. Light Scattering & Remote Sens. (ISALSaRS'11)*, Lanzhou, China, June 20-24.

Sun-Mack, S., P. Minnis, F.-L.Chang, Y. Chen, P. Heck, Y. Yi, Q. Trepte, R. Arduini, S. Gibson, R. Smith, R. Brown, E. Heckert, and D. Winker, 2011: CERES Edition 4 cloud properties. *Intl. Symp. Atmos. Light Scattering & Remote Sens. (ISALSaRS'11)*, Lanzhou, China, June 20-24.

Cloud Parameters in both CERES Edition 2 and Edition 4

Ice eff diameter (3.7 µm) → Smooth --> Rough ice crystal ref models
Diameter De → effective radius Re

Visible optical depth → (1) Increased limit from 128 to 150
(2) Ozone attenuation correction
(3) Rough models in VISST ice cloud retrieval yield different optical depths

Liquid and ice water path → Rough models in VISST ice cloud retrieval yield different ice water path

Retrievals over snow/ice → Optical depth from 1.6/2.1 µm → optical depth from 1.24 µm

Cloud Parameters in both CERES Edition 2 and Edition 4

cloud top pressure, temp & height
cloud effective pressure, temp & height
cloud base pressure, temp & height

→ (1) New seasonal & regional boundary-layer lapse rate,
(2) New thickness & physical top parameterizations
(3) CO2 heights used when VISST too low

Liquid water droplet
Cloud mask
Cloud phase

→ All improved, coding errors fixed

Cloud Parameters in CERES Edition 2

Cloud Mask, Phase
Optical Depth, IR emissivity
Effective Radius/Diameter
Liquid/Ice Water Path
Cloud Effective Temperature
Cloud Top/ Bottom Pressure
Cloud Effective Pressure
Cloud Effective Height
Clear-sky Temperature

All data only available in SSF or 1° averages

New Cloud Parameters in CERES Edition 4

New Size Retrievals
Water droplet eff radius (1.24 μm)
Ice effective radius (1.24 μm)
Water droplet eff radius (2.1 μm)
Ice effective radius (2.1 μm)

CO2 Slicing
Cloud Top Pressure
Cloud Top Temperature
Cloud Top Height
IR Emissivity

Multilayer Cloud Retrieval	(Ice Over Water)
Multilayer Identification	
Upper Layer (Ice Clouds)	Lower Layer (Water Clouds)
Cloud Top Pressure	Cloud Top Pressure
Cloud Top Temperature	Cloud Top Temperature
Cloud Top Height	Cloud Top Height
Cloud Visible Optical Depth	Cloud Visible Optical Depth
Ice Effective Radius (3.7 μm)	Water Droplet Radius (3.7 μm)
Ice Effective Radius (2.1 μm)	Water Droplet Radius (2.1 μm)

All data only available in SSF, 1° averages, & at pixel level

Edition 4 Delivered in May

(1) Implemented Terra calibrations for 7 MODIS bands (0.6, 0.87,1.24, 2.13, 0.47, 0.55 and 1.38 μm) for radiances & reflectance

(2) Due to above (1) calibration changes, snow-free and snow-covered directional models for 1.24 μm were re-created

(3) Due to above (1) calibration changes, monthly start-up maps for snow-free and snow-covered for 0.6, 1.24 and 2.13 μm were re-generated

(4) Modified cloud phase algorithm to recover missing supercooled clouds

(5) Improved cloud mask retrieval over polar regions (?)

(6) Improved final mask (combined cloud mask, VISST retrieval and CO2 slicing retrievals) to remove false clouds, likely to be aerosols

(7) Removed fill-no-retrieval process (fill with LBTM or neighboring avg value, if no-retrieval) for 1.24 & 2.1-μm size retrievals

(8) Corrected faulty upper-layer cloud optical depths for multi-layered clouds

(9) Implemented new default for SIST (night time retrieval) particle size pegging issues, that is we hit the largest or smallest value of Re/re

(10) Jin's visible clear sky ocean TOA reflectance model used std atmosphere. Clouds subsystem calculated clear ocean reflectance with water vapor & ozone absorption using MOA profiles. Added modifications to ensure consistency.

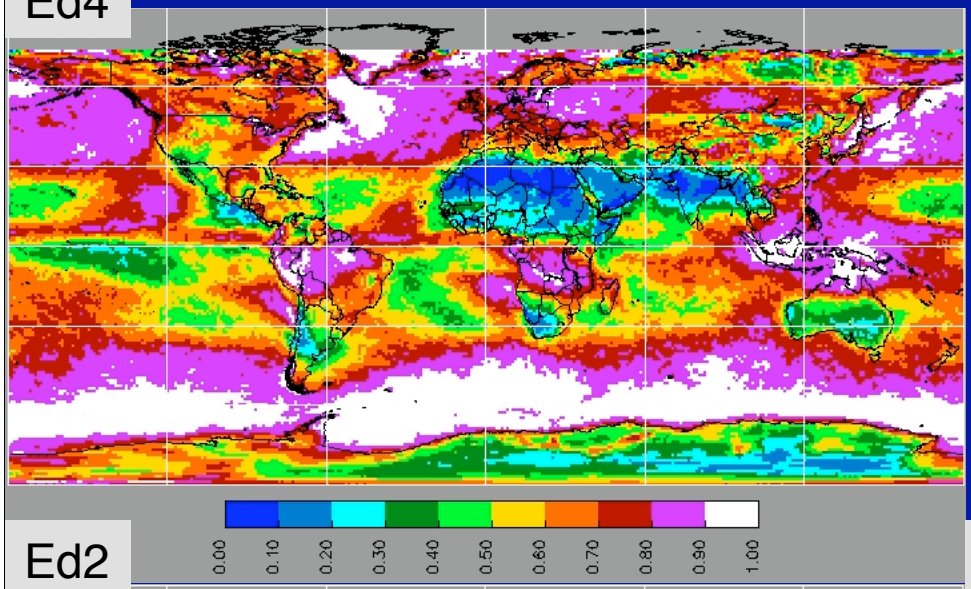
Edition 4 First Results September 19

- 2000 - 2001 Terra results

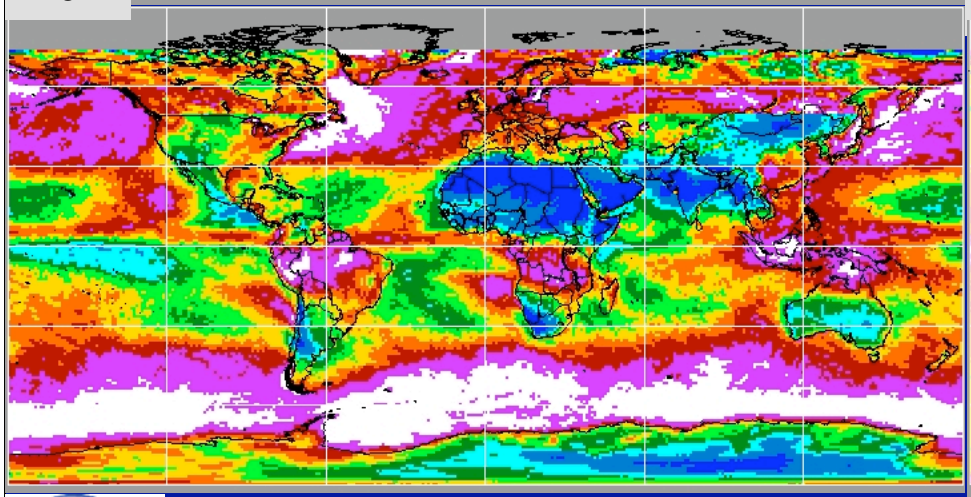
  - subject of this presentation

Total Daytime Cloud Fraction: CERES Ed 2 versus Ed 4
Winter 2000/2001

Ed4

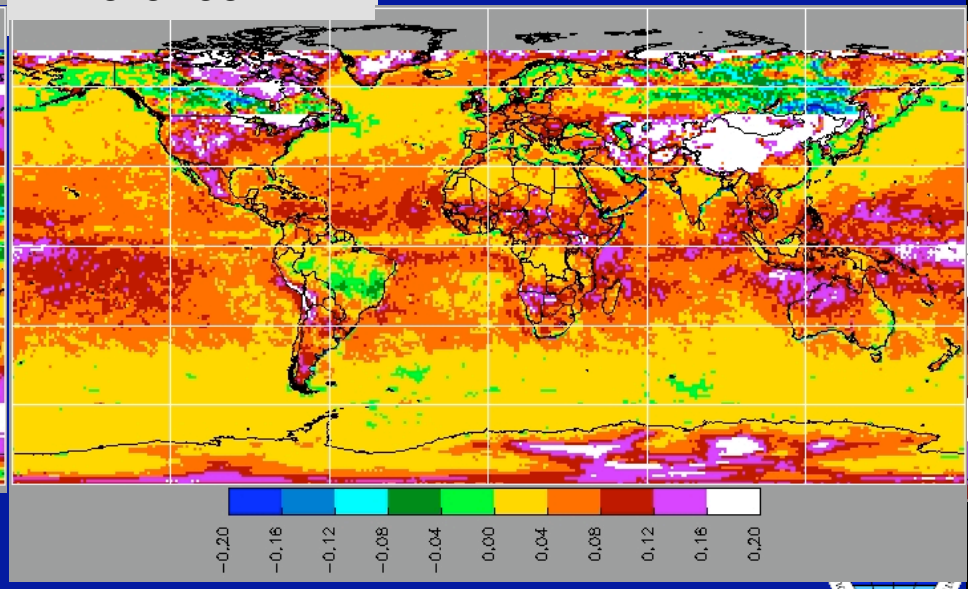


Ed2



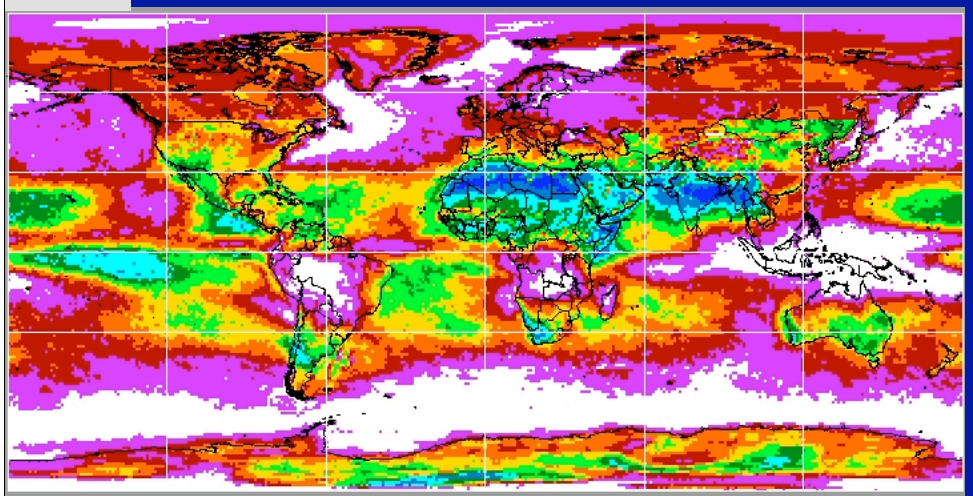
- Increased cloud amounts everywhere except Brazil, Arctic lands
- Trade Cu and dry high altitude greatest increases
- Polar line still evident at 50°N
  - not as prominent

Difference



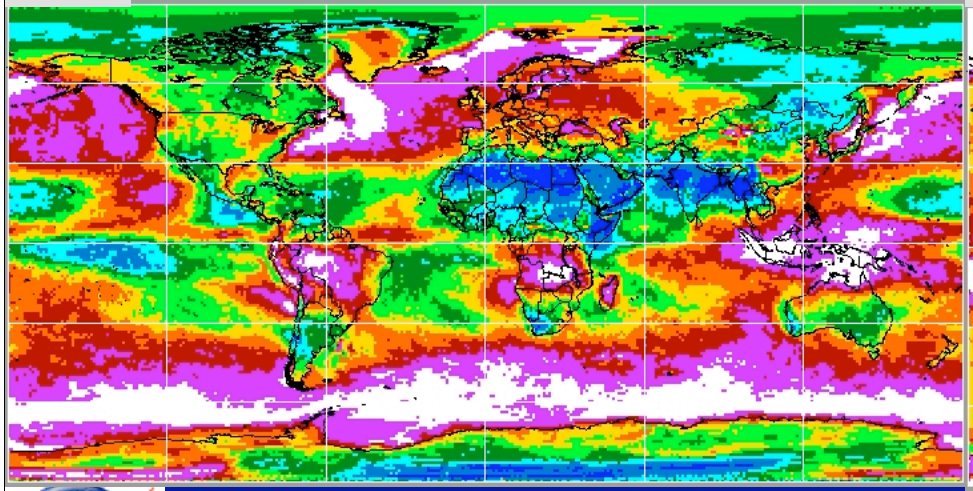
Total Night Cloud Fraction: CERES Ed 2 versus Ed 4
Winter 2000/2001

Ed4

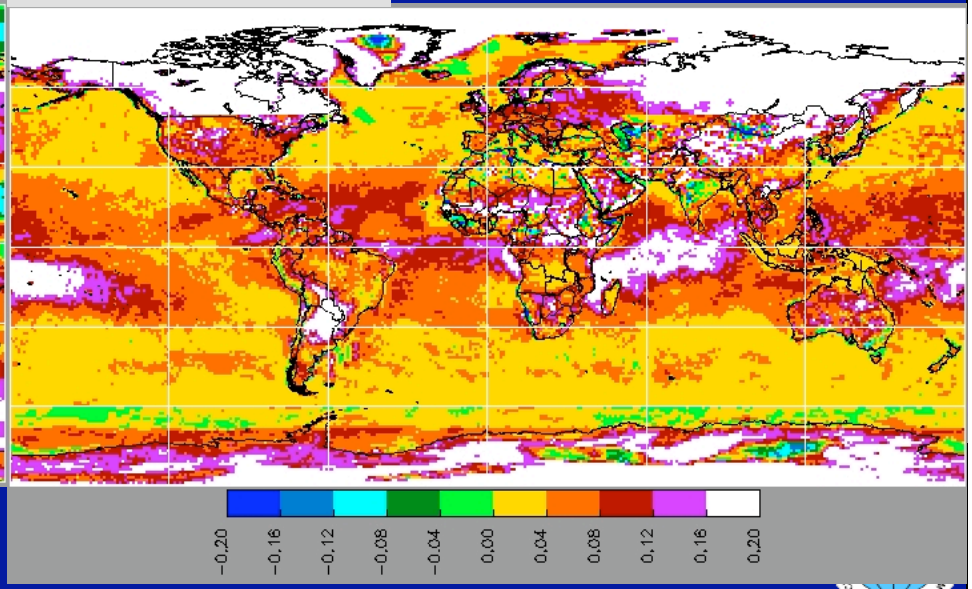


- Increased cloud amounts nearly everywhere
- Trade Cu and polar regions greatest
- Polar line more evident at 50°N

Ed2

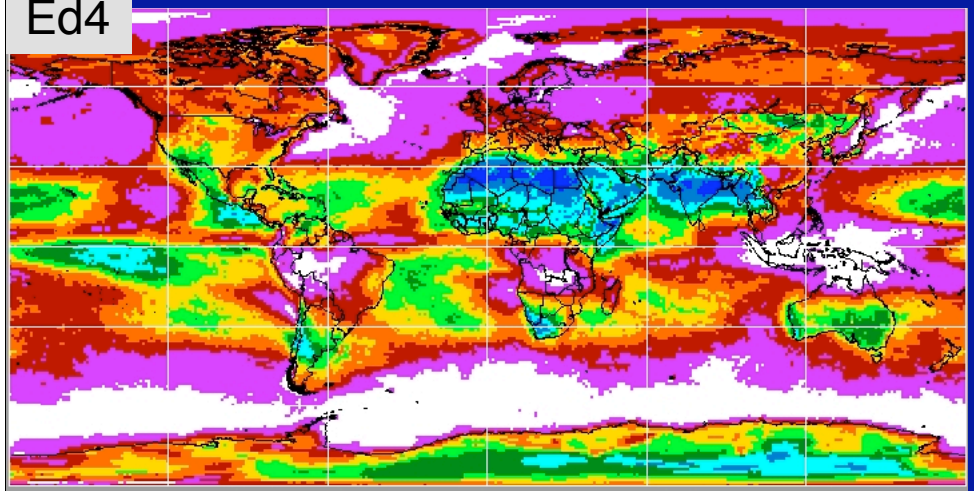


Difference

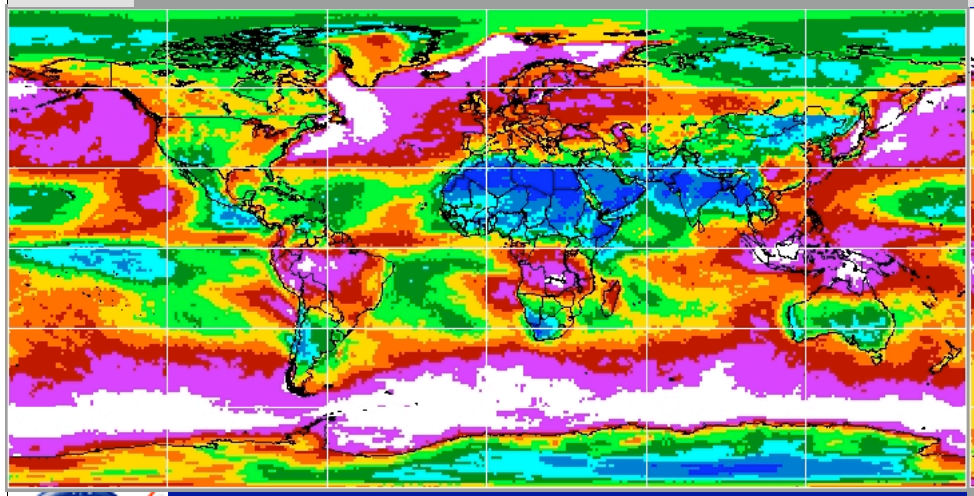


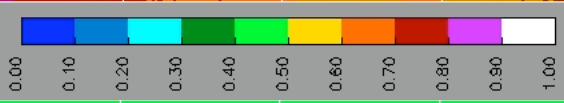
Total Cloud Fraction: CERES Ed 2 versus Ed 4
Winter 2000/2001

Ed4



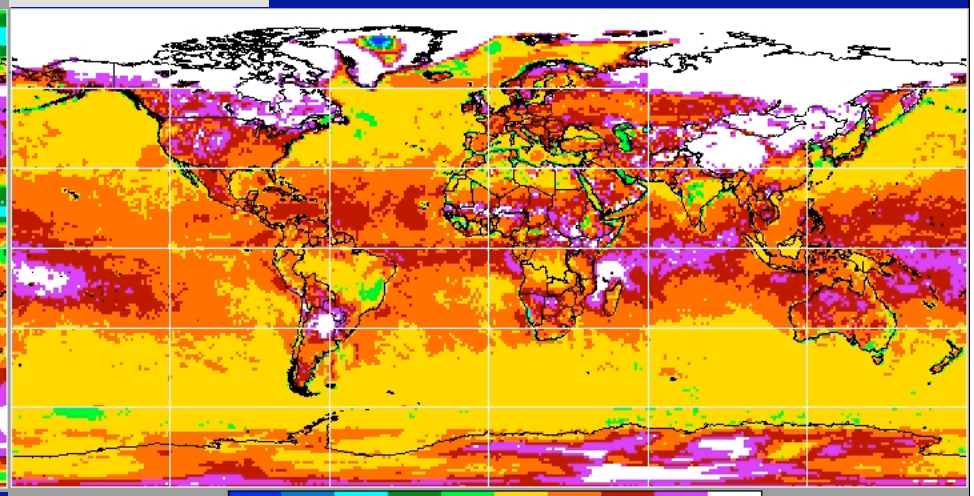
Ed2

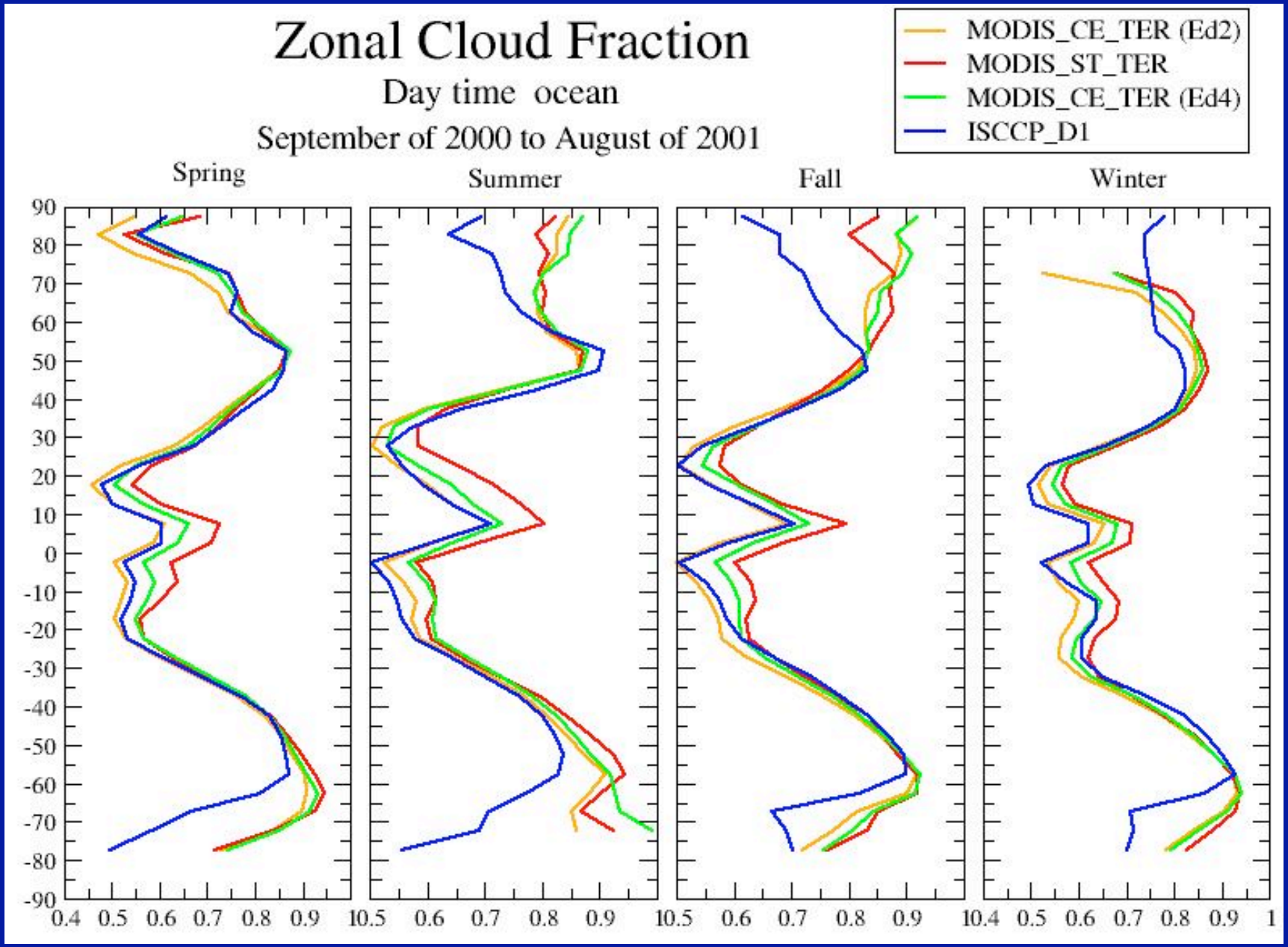




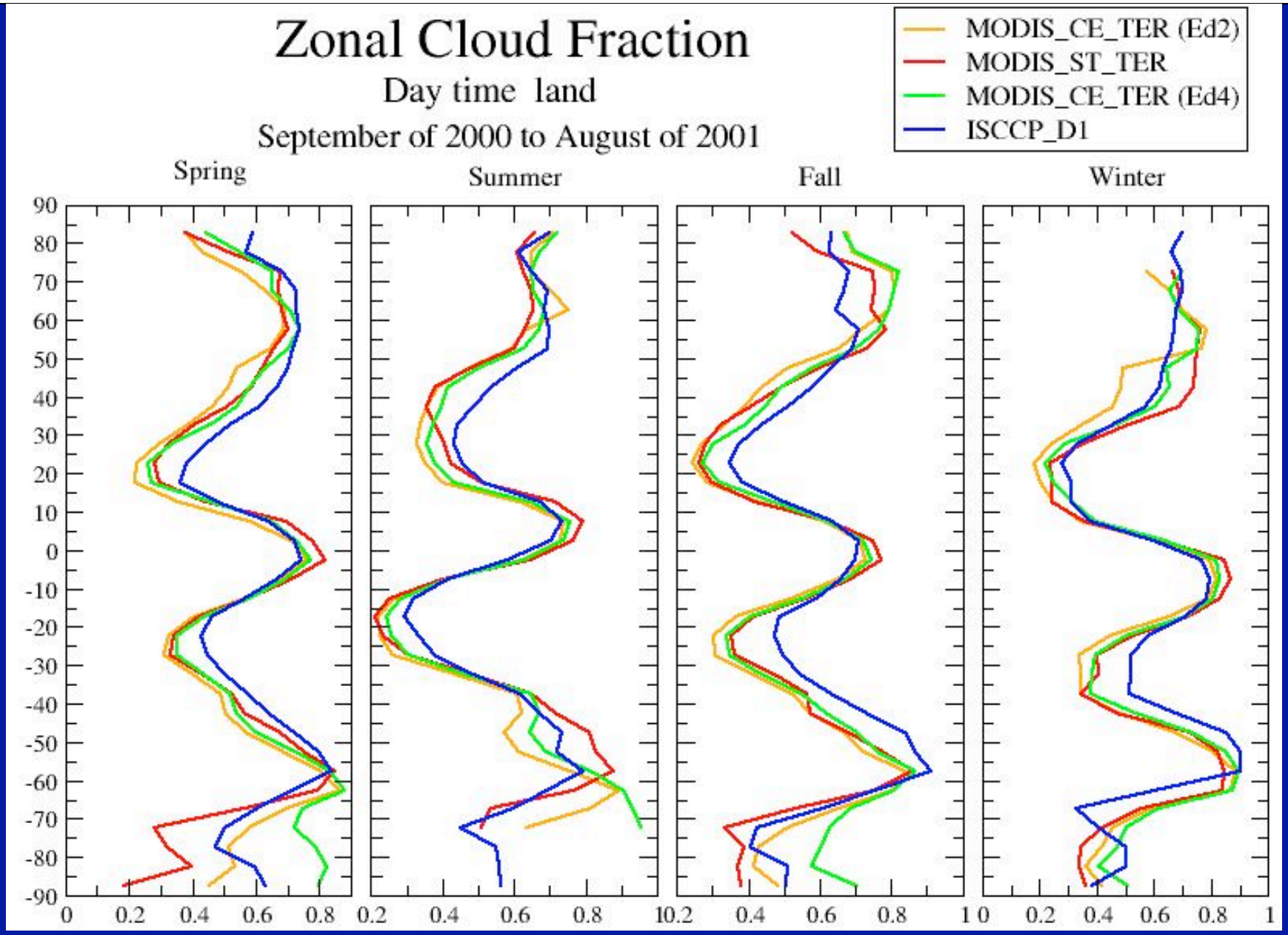
- Increased cloud amounts nearly everywhere
- Trade Cu and dry high altitude greatest increases
- Polar line worst in Siberia

Difference

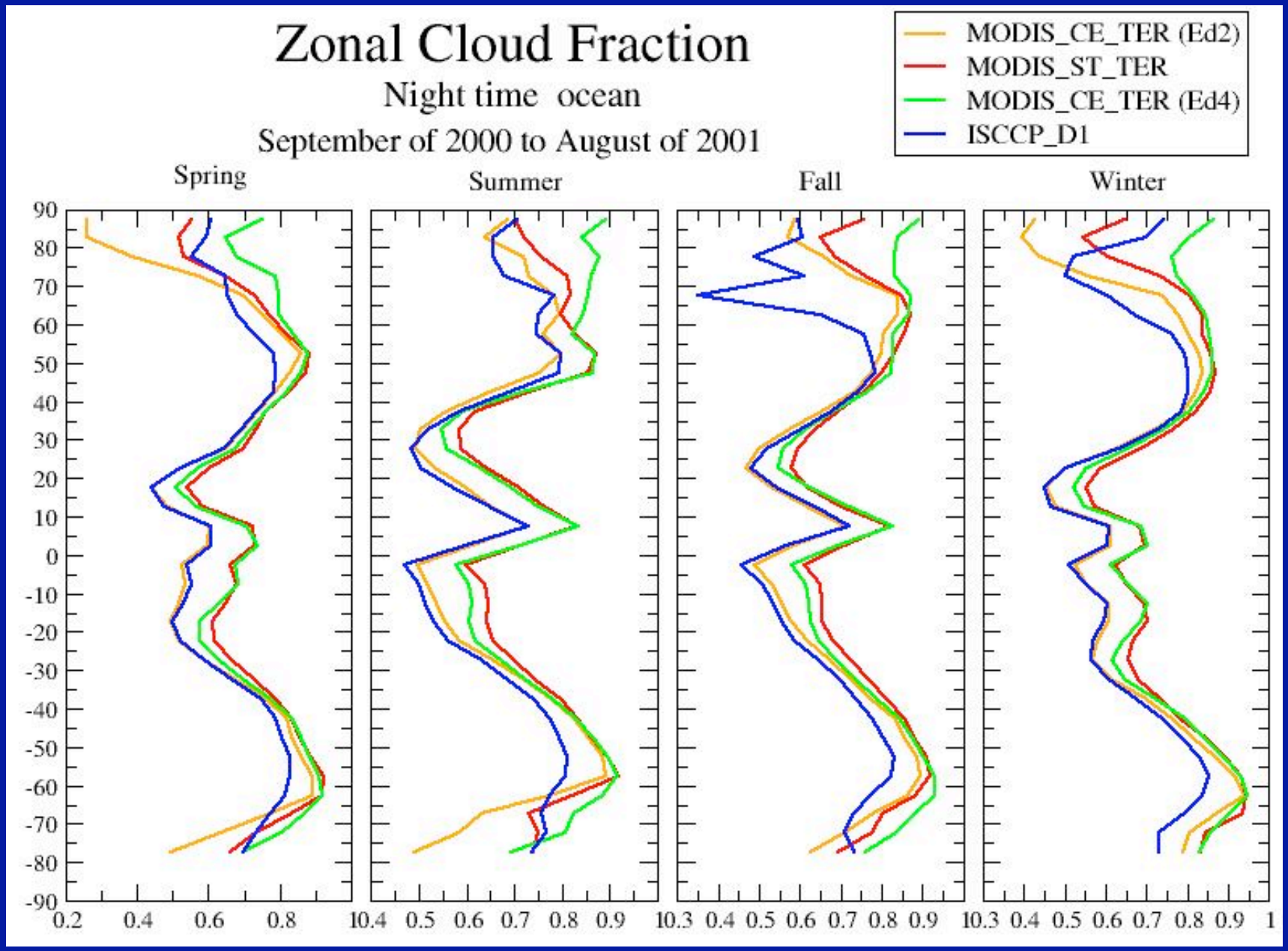




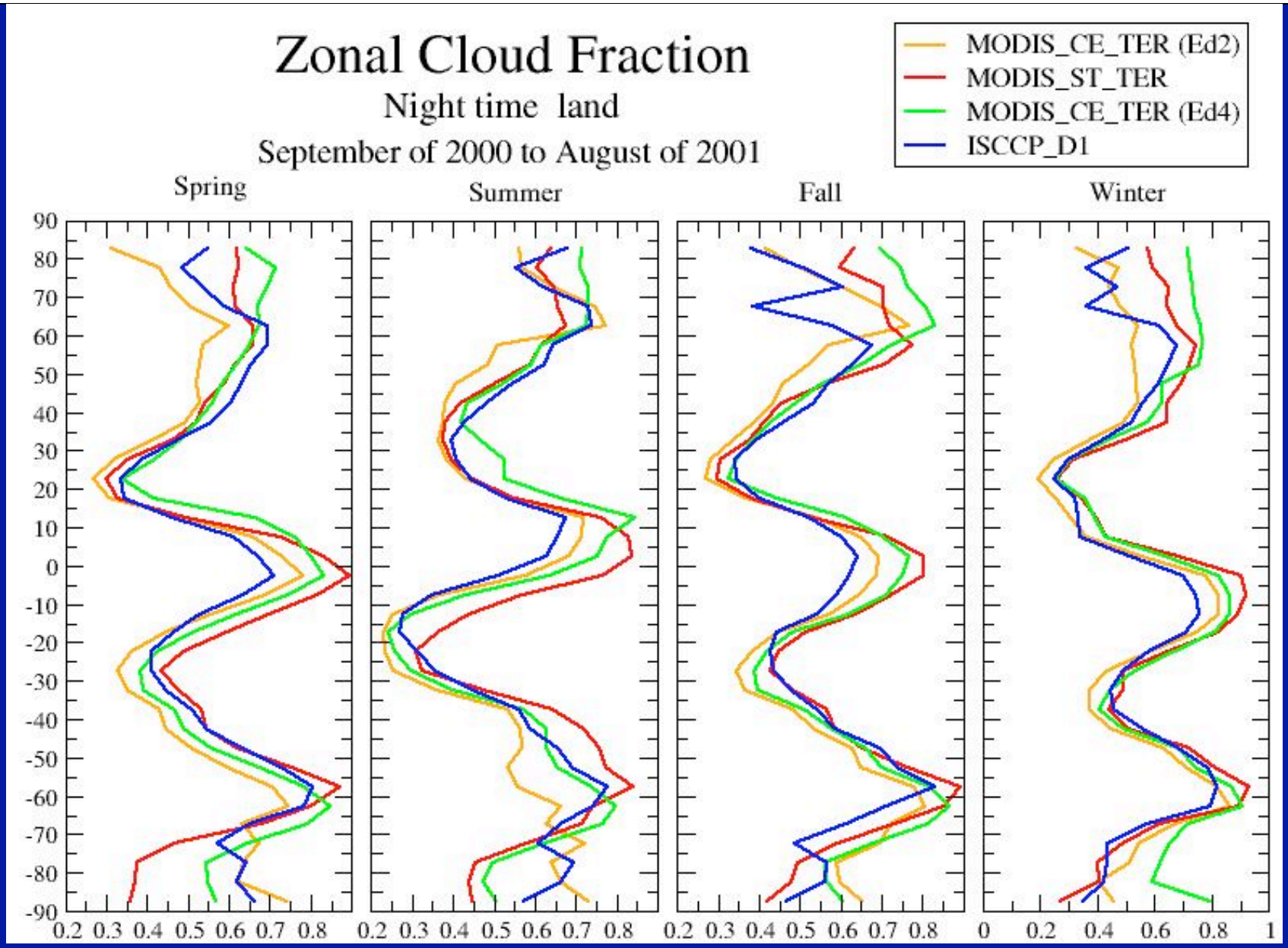
Daytime over ocean looks good except perhaps near Antarctic ice sheet in austral spring



Daytime over land looks good except perhaps near Antarctic in spring and fall

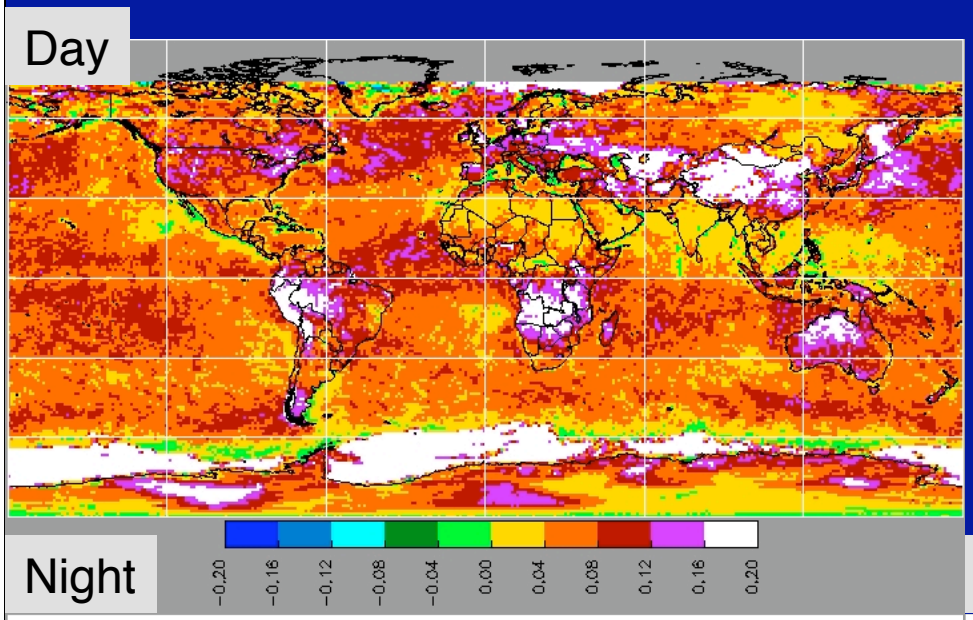


Night over ocean looks good except Arctic

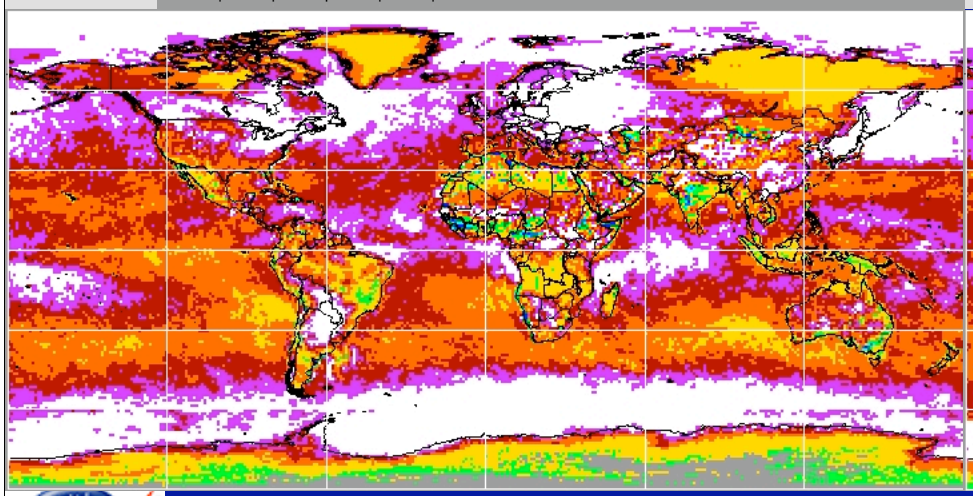


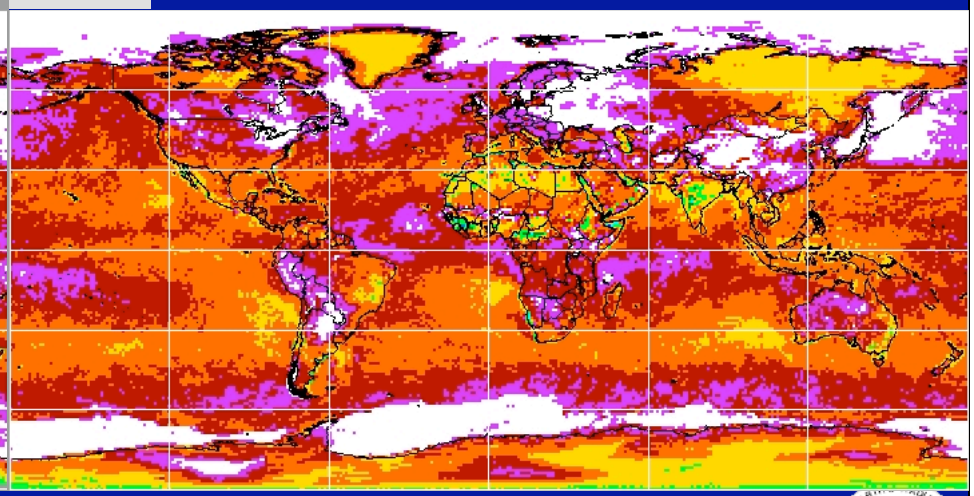
Night over land looks good except Arctic, maybe northern tropics

Liquid Cloud Fraction Difference: CERES Ed 2 minus Ed 4
Winter 2000/2001

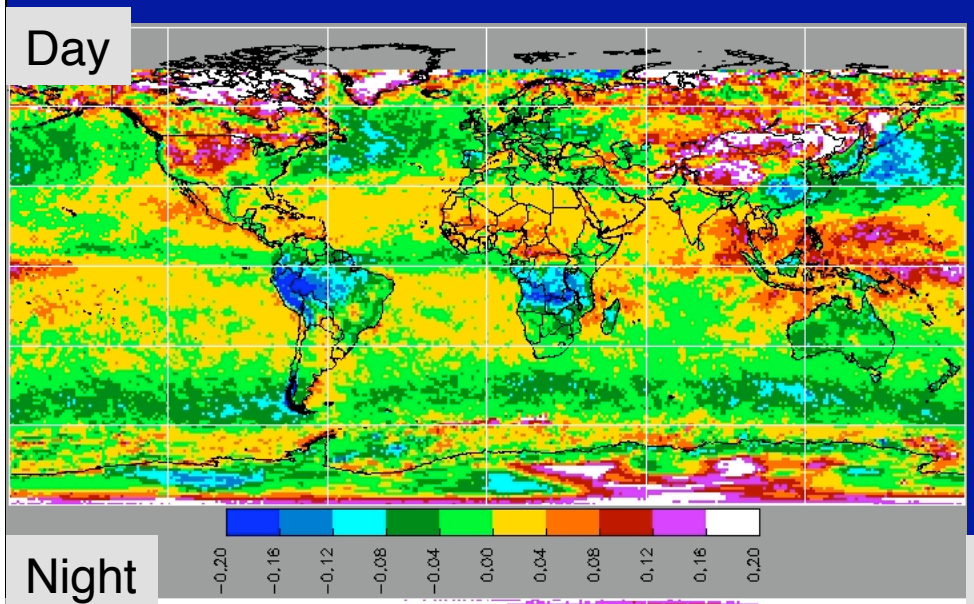


- Increased liquid cloud amounts nearly everywhere during day & night
- Greatest during day in highlands
- Greatest at night over mid-high latitudes

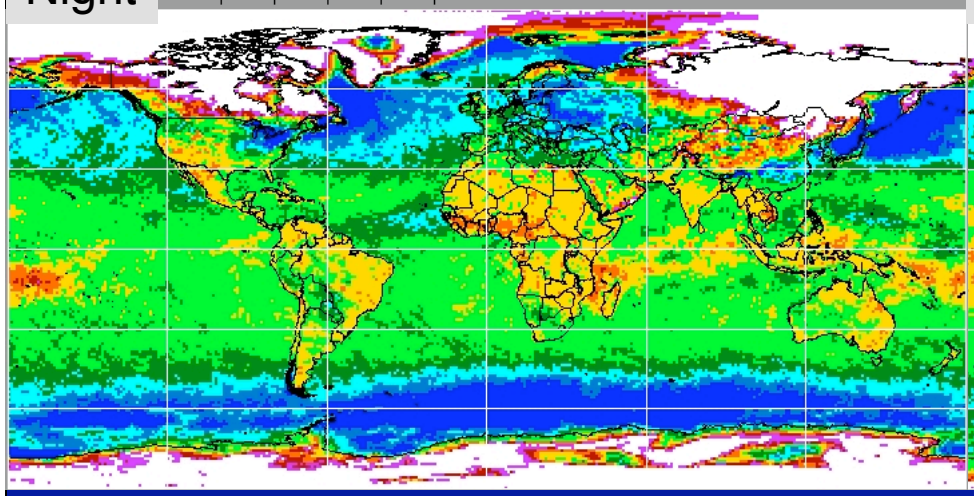


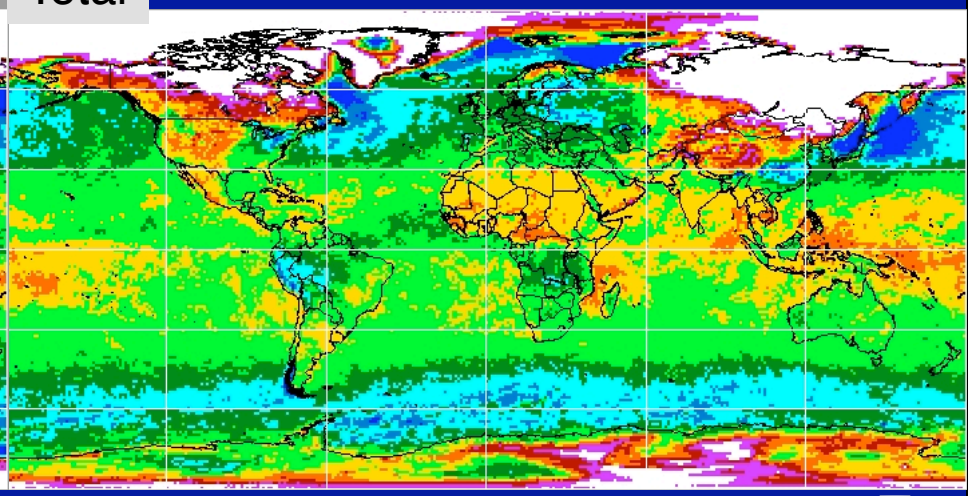


Ice Cloud Fraction Difference: CERES Ed 2 minus Ed 4
Winter 2000/2001



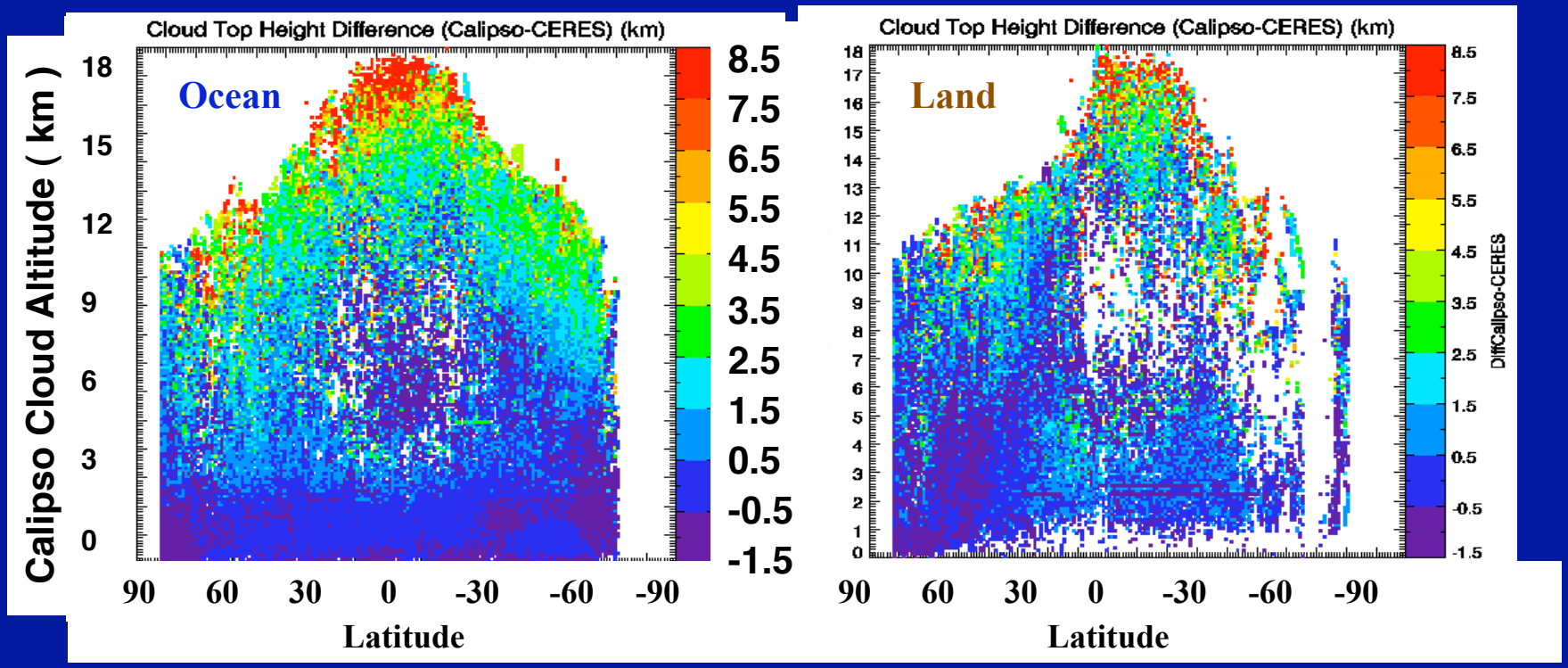
- Increased cloud amounts only in ITCZ, polar land, & some high altitude
- Increase in liquid over mid-lat ocean mainly at the expense of ice clouds
- Arctic night & Siberia see greatest increases





Ed 2 Zonal Cloud Top Height Difference (km) vs Cloud Altitude

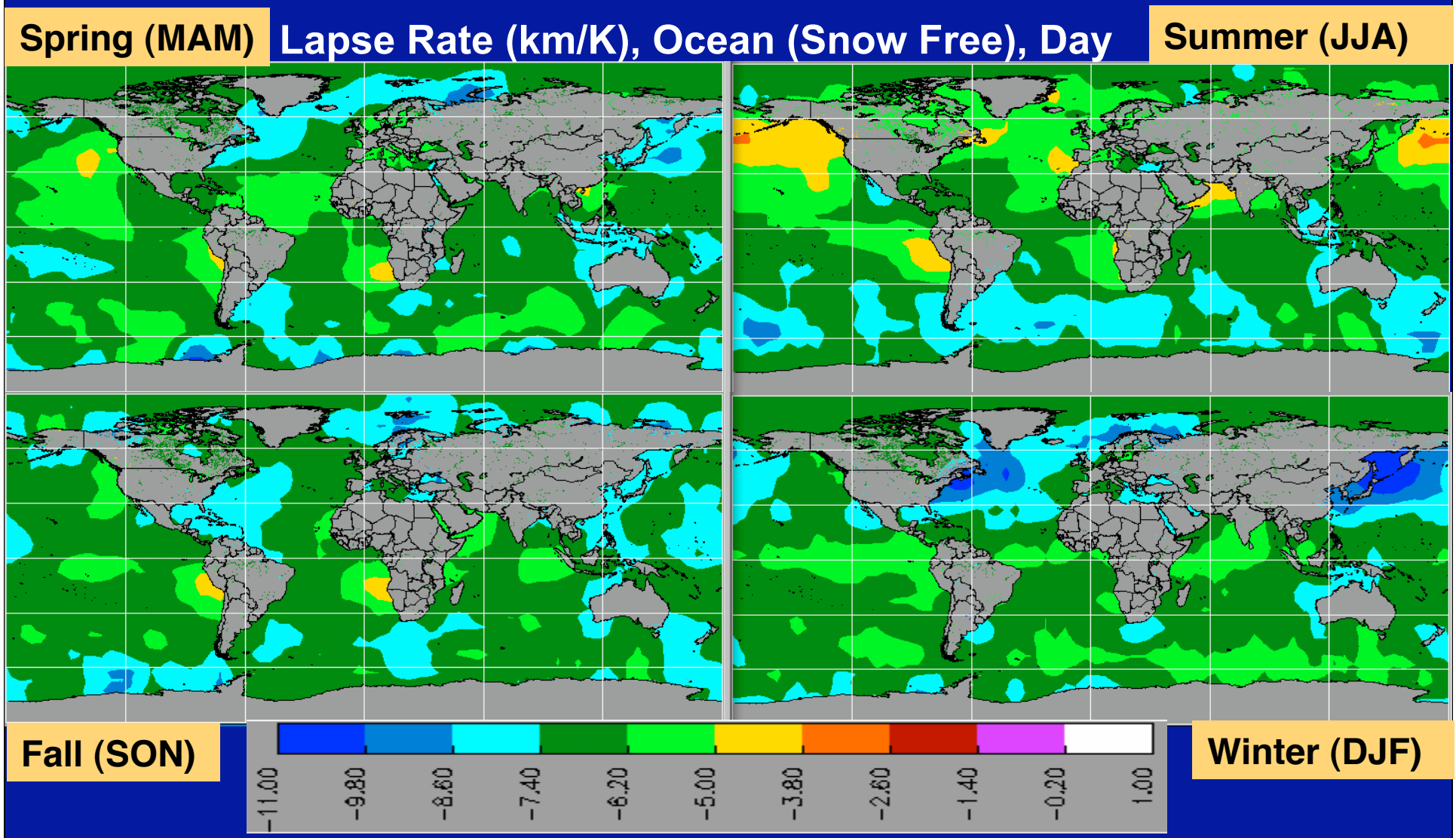
April 2007



CERES effective heights consistent with other studies

- low clouds ± 0.5 km over ocean, slightly greater over land
- high clouds typically > 2 km underestimate

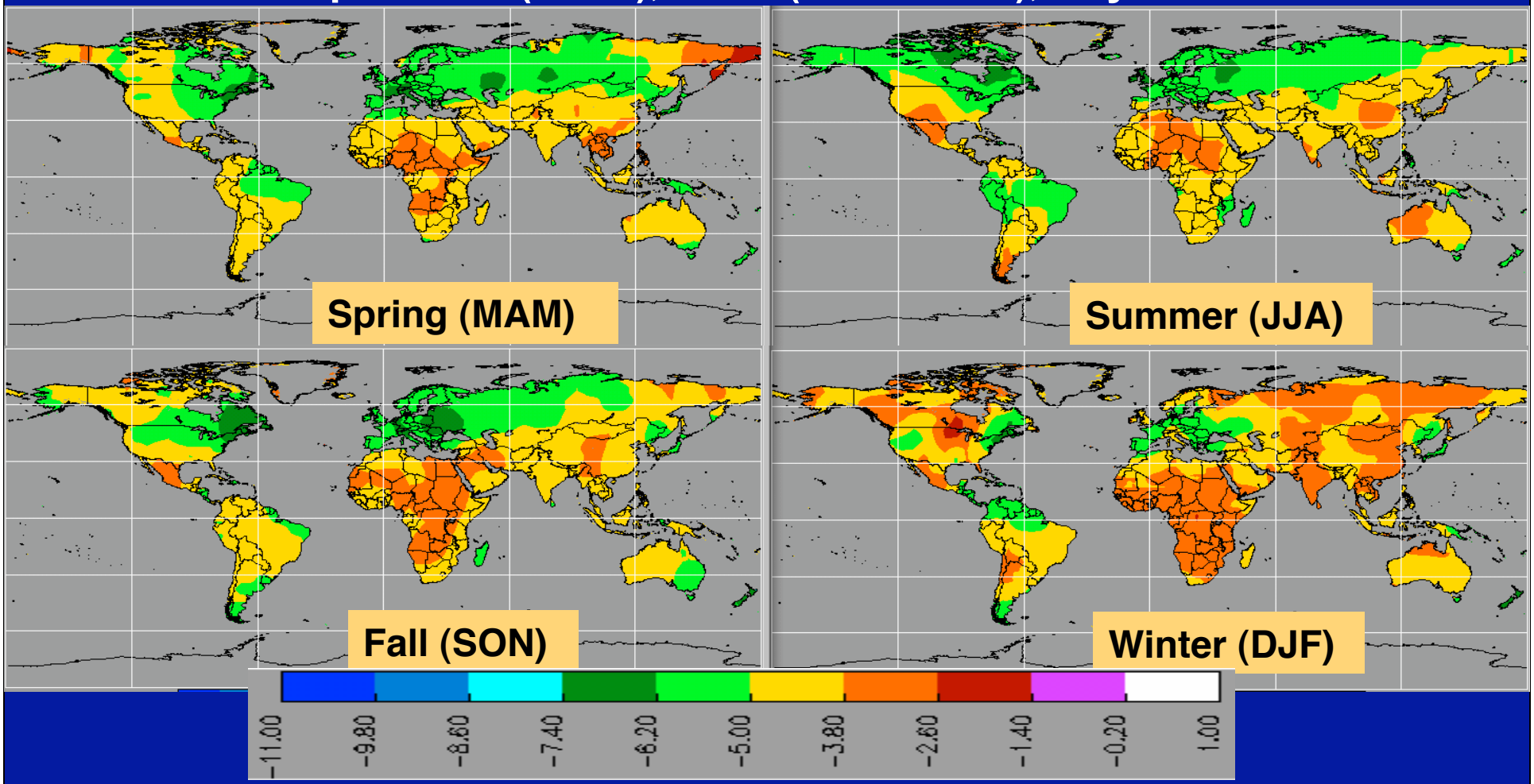
Daytime Ed 4 Boundary Lapse Rates from CALIPSO/MODIS



- Replaced a constant 7.1 K/ km lapse rate for Ed2

Daytime Ed 4 Boundary Lapse Rates from CALIPSO/MODIS

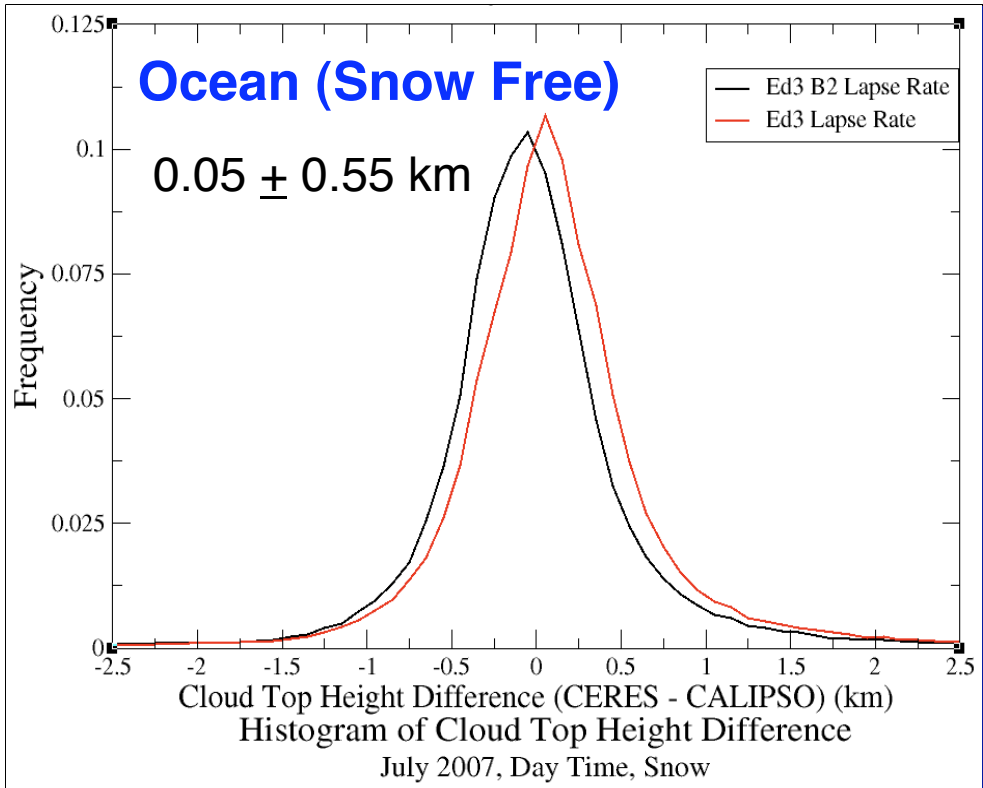
Lapse Rate (km/K), Land (Snow Free), Day Time

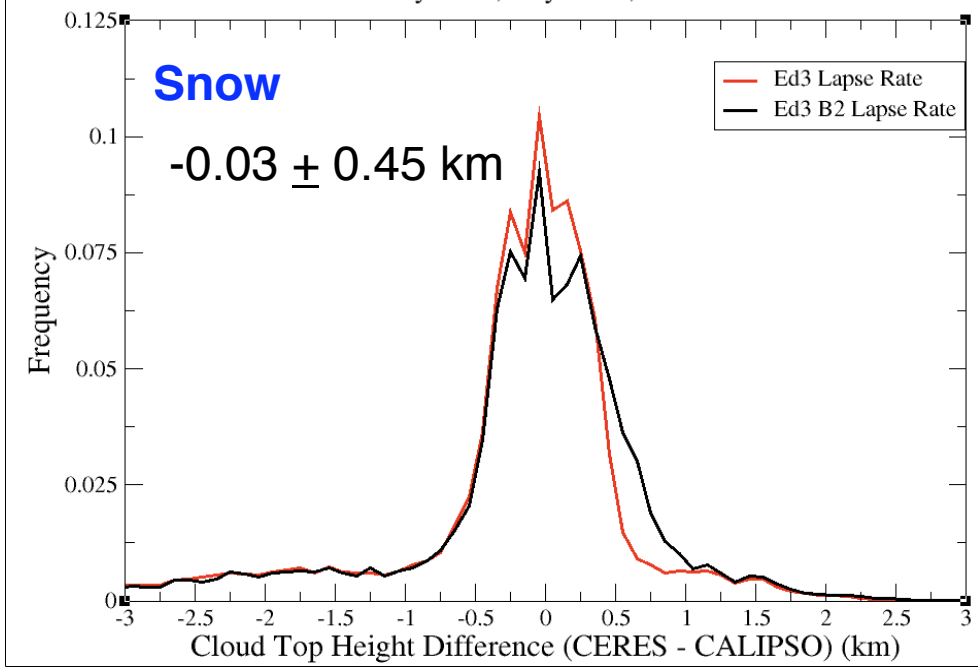


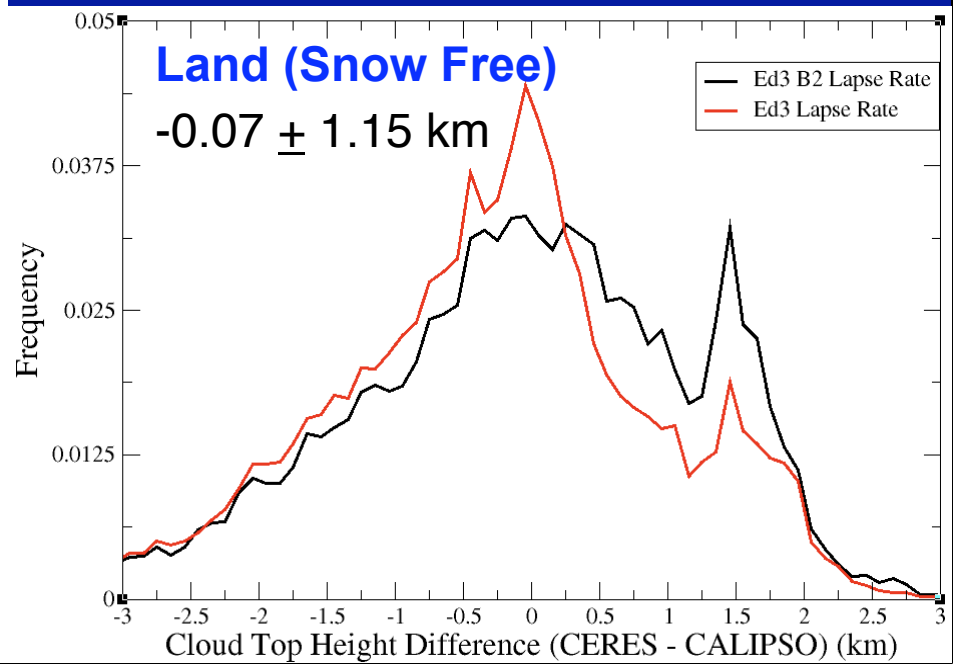
- Replaced a constant 7.1 K/ km lapse rate for Ed2

Boundary-layer Cloud Top Height Differences: CALIPSO - Ed4 December 2007 Daytime

- Ed2 bias over land gone
  - high variability
- Ocean/snow low cloud height errors acceptable

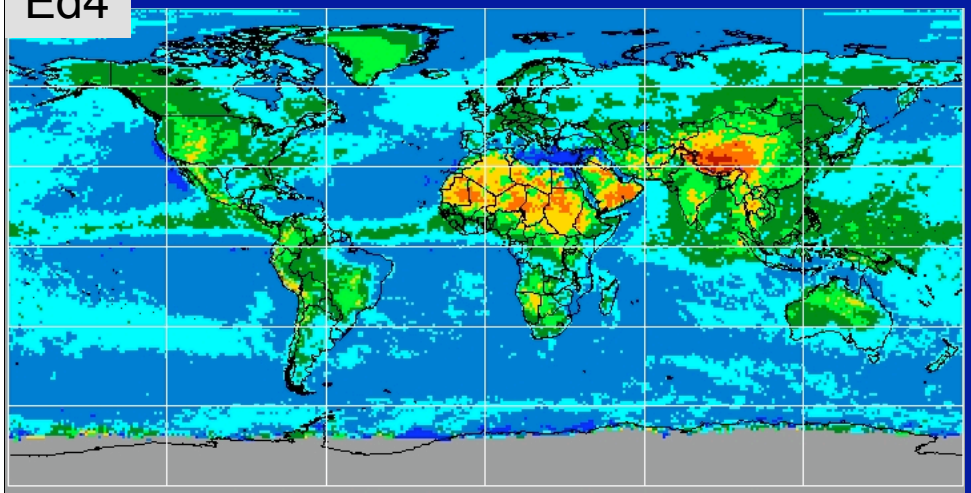


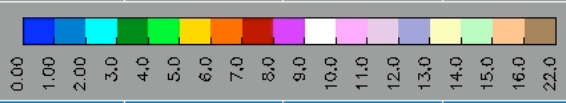




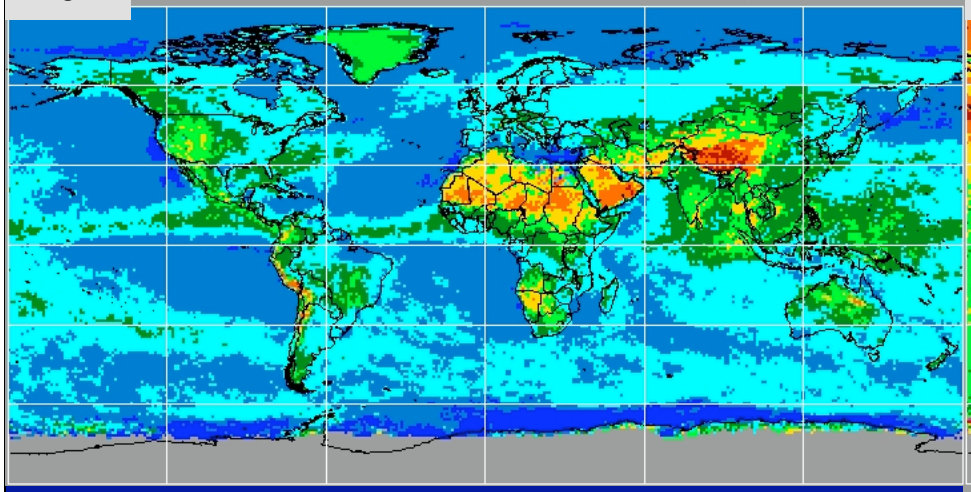
Total Daytime Low Cloud Height: Ed 2 versus Ed 4
Summer 2000/2001

Ed4

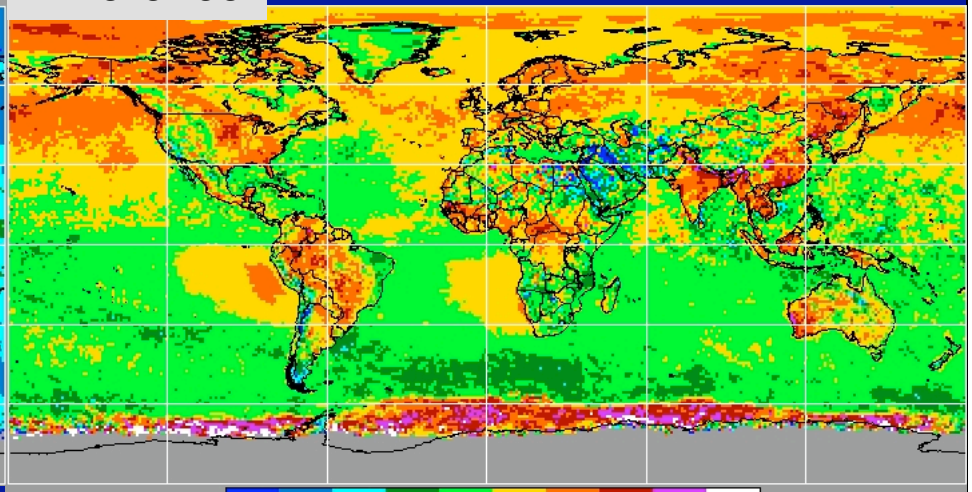


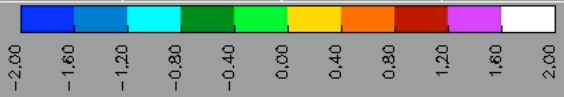


Ed2



Difference

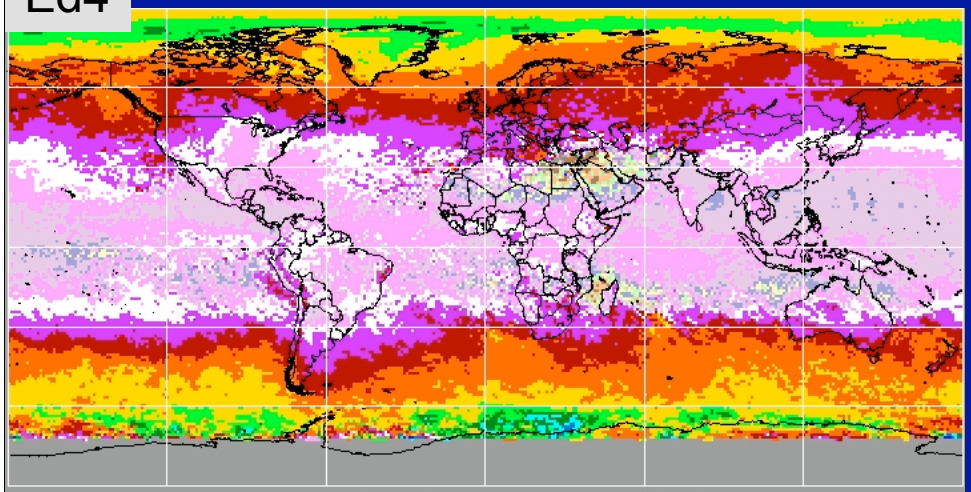




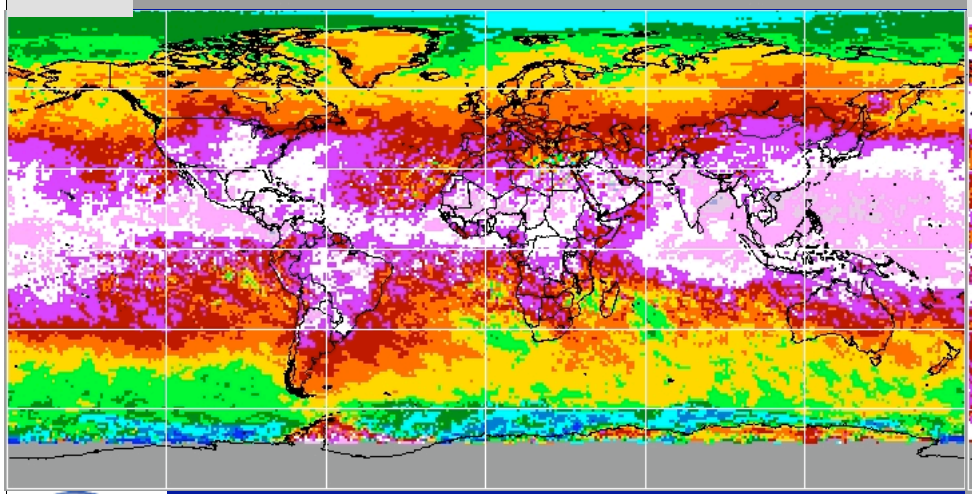
- Increased heights over marine stratus and some land areas
- Slight decreases in many areas

Total Daytime High Cloud Height: Ed 2 versus Ed 4
Summer 2000/2001

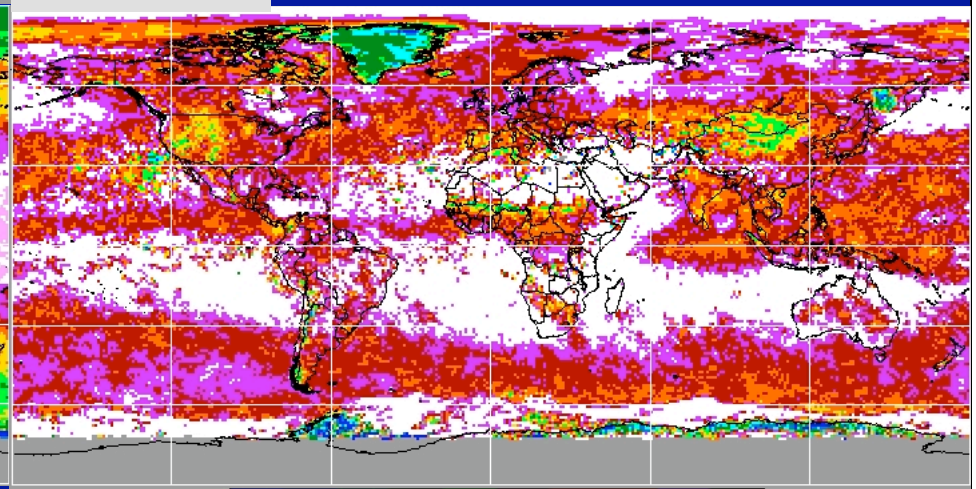
Ed4

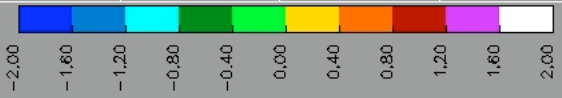


Ed2



Difference

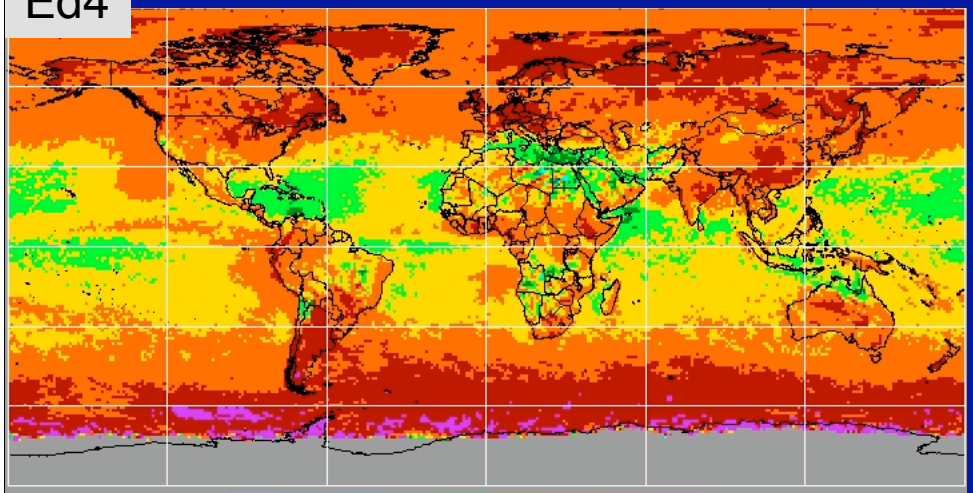




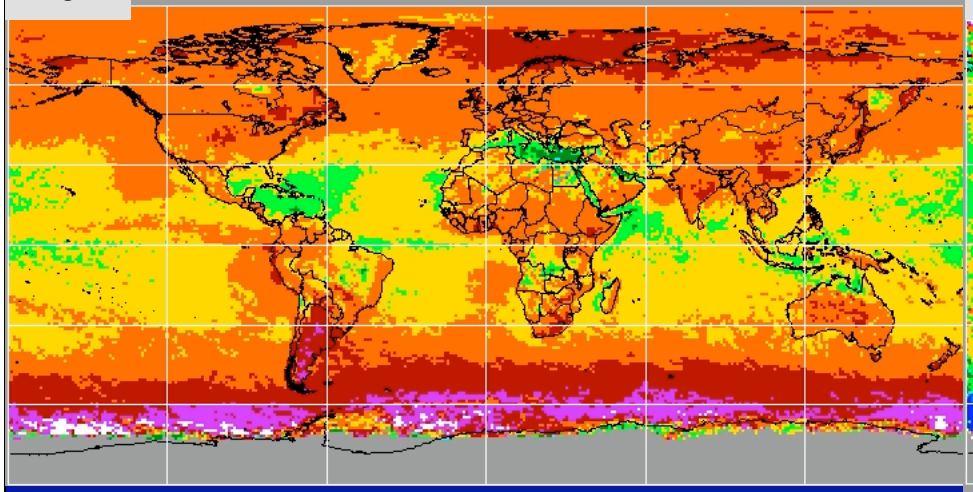
- Increased heights nearly everywhere
- Change in ice model and use of CO2-slicing method mainly responsible for increased heights

Daytime Liquid Cloud Optical Depth: Ed 2 versus Ed 4
Summer 2000/2001

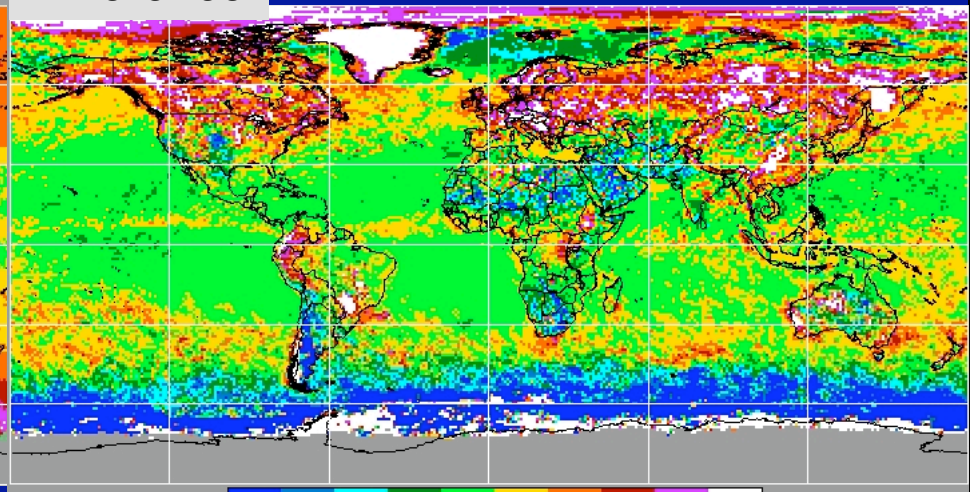
Ed4

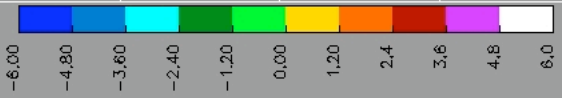


Ed2



Difference

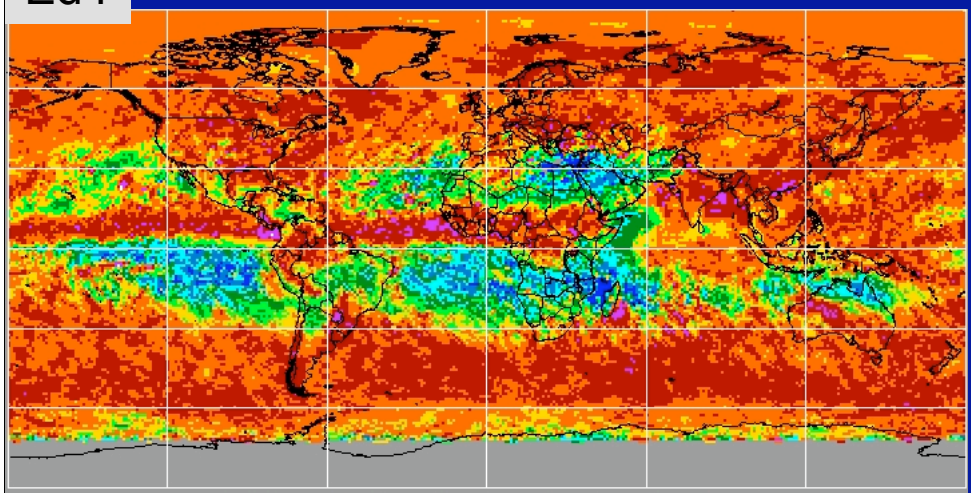




- Increased cloud amounts over tropics mostly optically thin clouds => τ drops
- Mid-latitude clouds formerly ice increase τ
- Arctic increases due to 1.24-μm τ
- *Hi-lat decrease due to O3 correction*

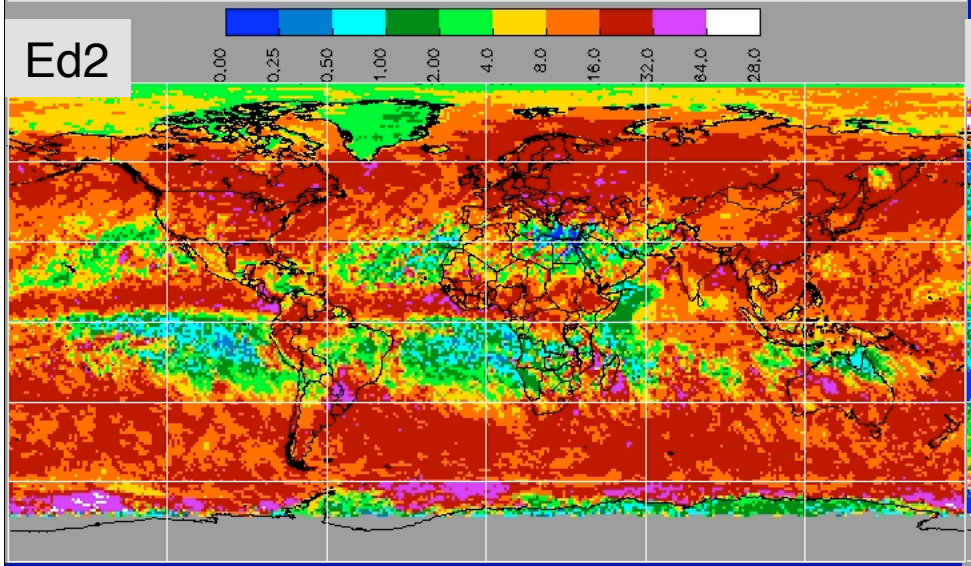
Daytime Ice Cloud Optical Depth: Ed 2 versus Ed 4
Summer 2000/2001

Ed4

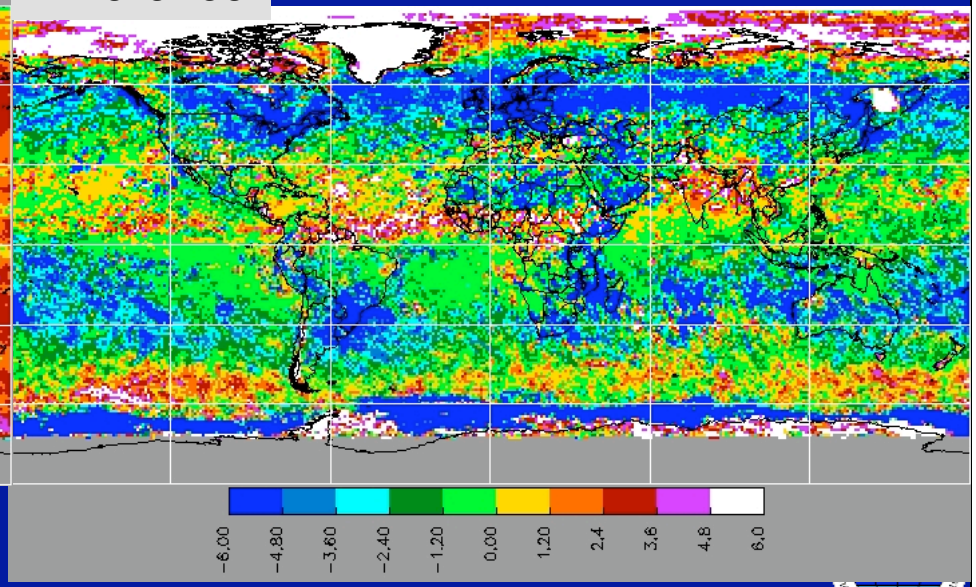


- Increase in limit from 128 to 150, τ rises in deep convective areas
- Mid-latitude clouds formerly ice decrease τ
- Arctic increases due to 1.24-μm τ

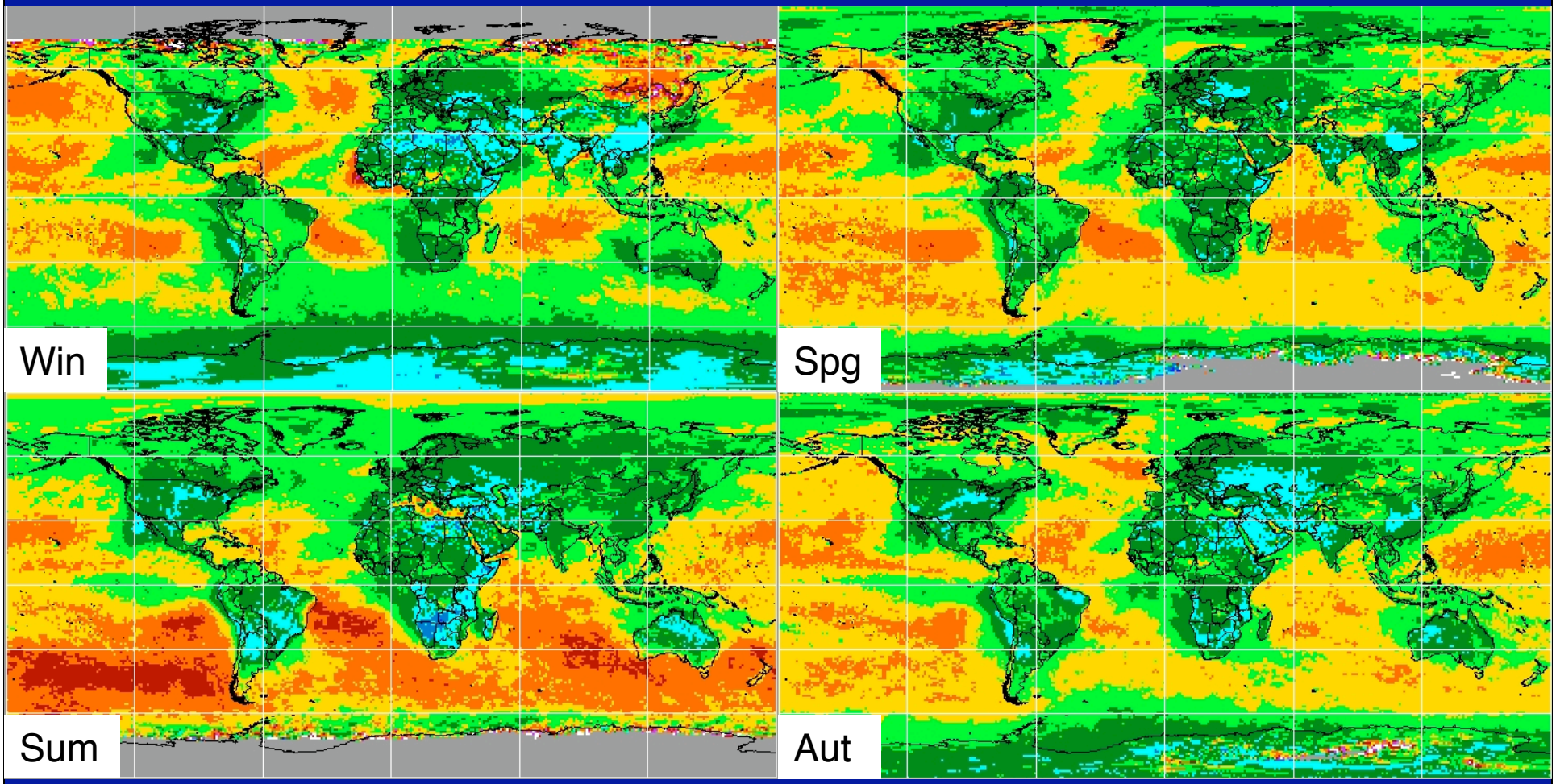
Ed2



Difference



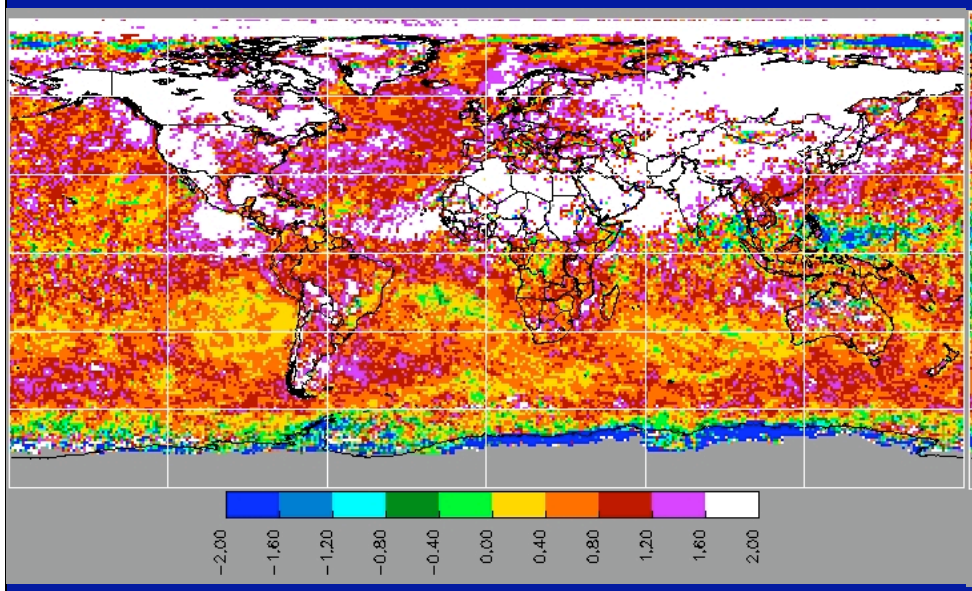
Seasonal Cycle of 3.7-μm Ed4 Droplet Re (μm)
Terra 2000/2001



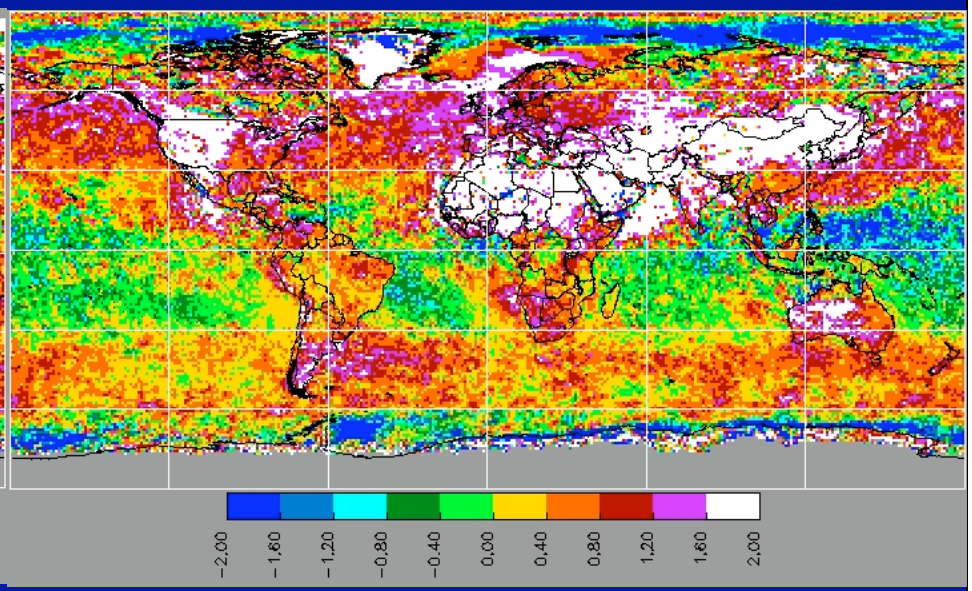
- Seasonal cycle very similar to Ed2 version, desert values greater

Mean Droplet 3.7-μm Re Difference: Ed2 – Ed4

Terra April 2001



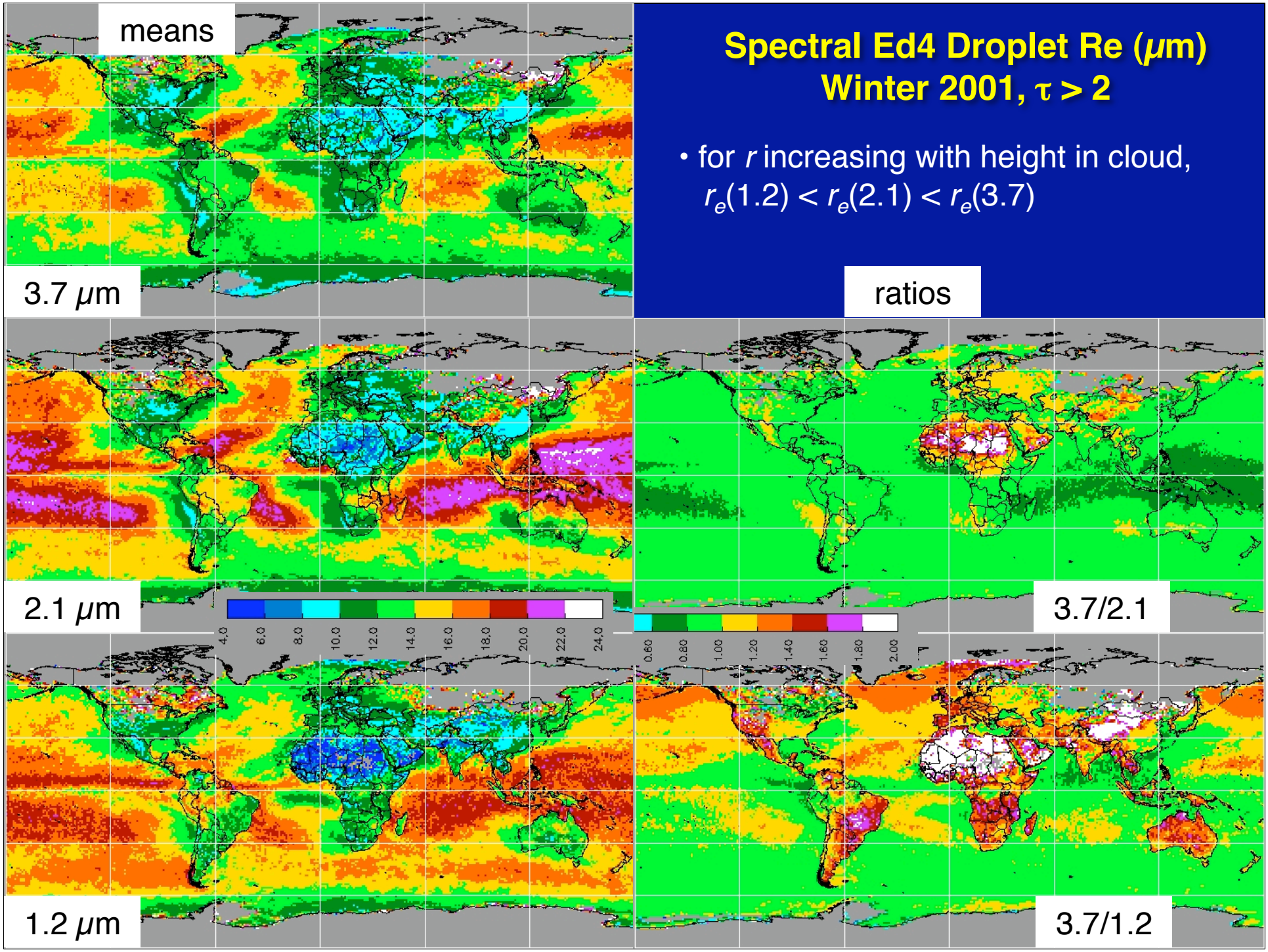
Aqua April 2008



- Increases over land due to phase changes & 1.24-μm snow OD retrieval
- General Terra increase of 0.5 – 1.5 μm from 3.7-μm calibration change
- Decrease in Aqua over ocean from phase change and pickup of tradeCu
  - some dust effects?

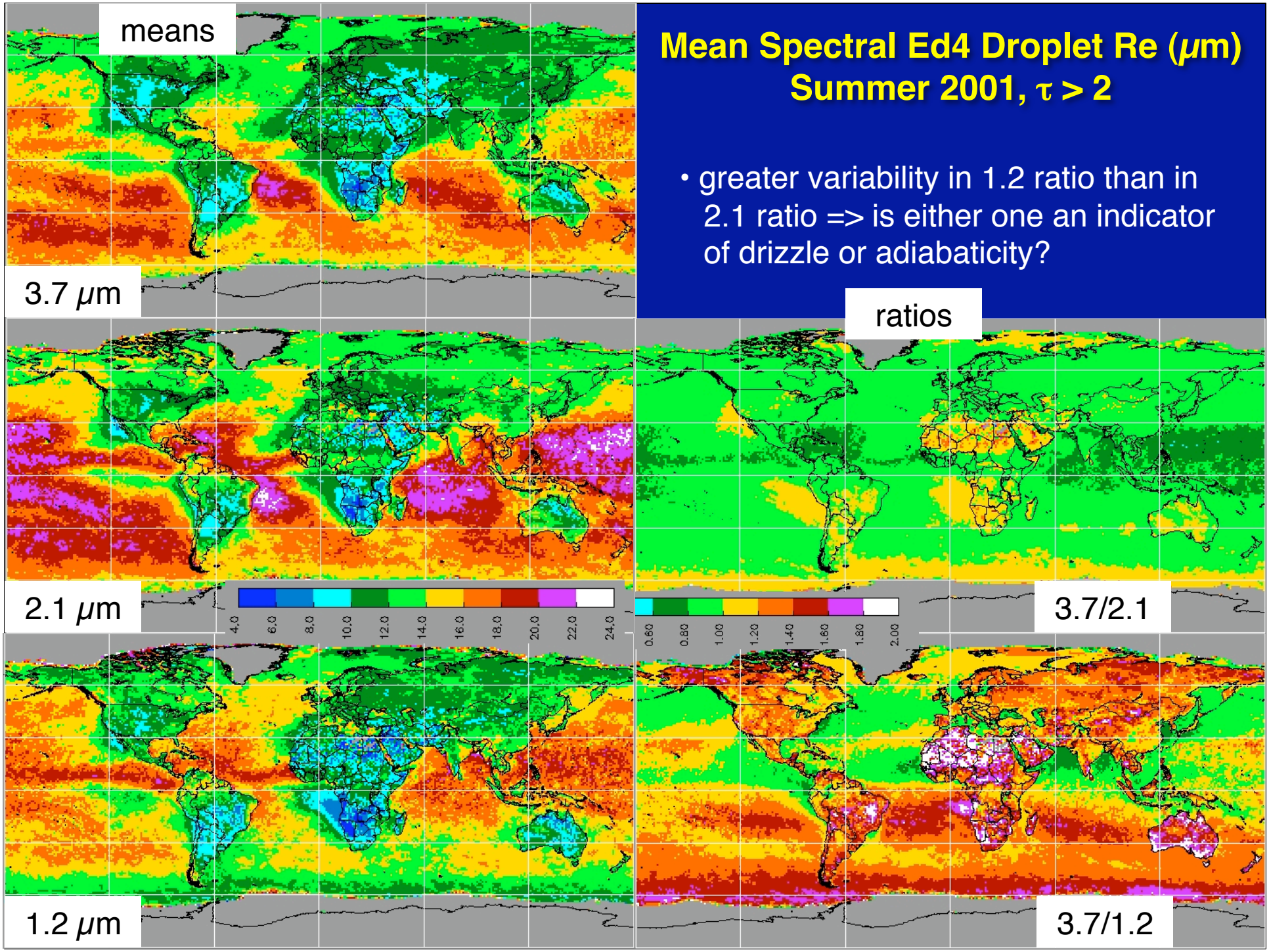
Spectral Ed4 Droplet Re (μm)
Winter 2001, $\tau > 2$

- for r increasing with height in cloud, $r_e(1.2) < r_e(2.1) < r_e(3.7)$



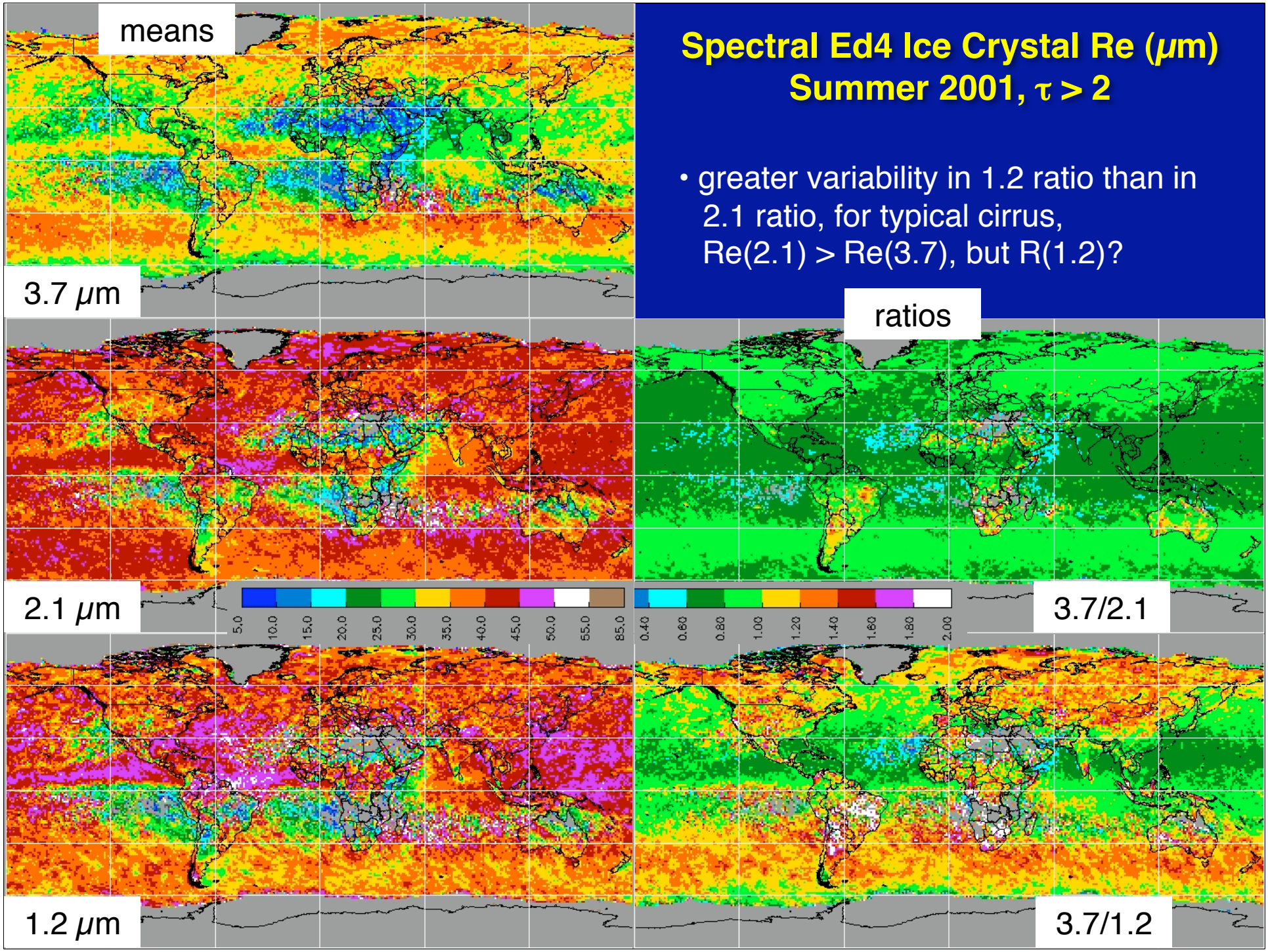
Mean Spectral Ed4 Droplet Re (μm)
Summer 2001, $\tau > 2$

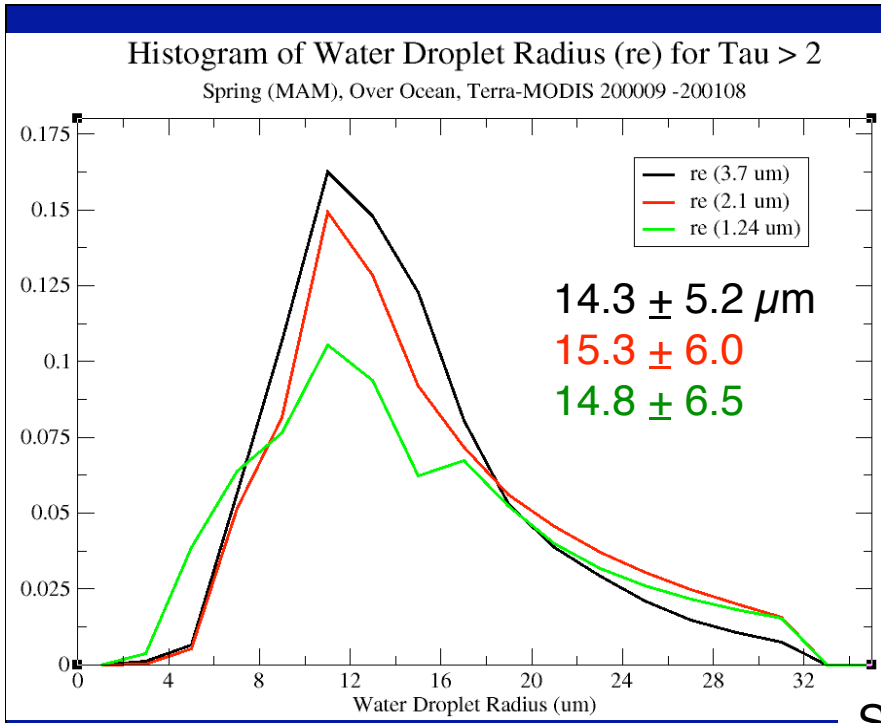
- greater variability in 1.2 ratio than in 2.1 ratio => is either one an indicator of drizzle or adiabaticity?

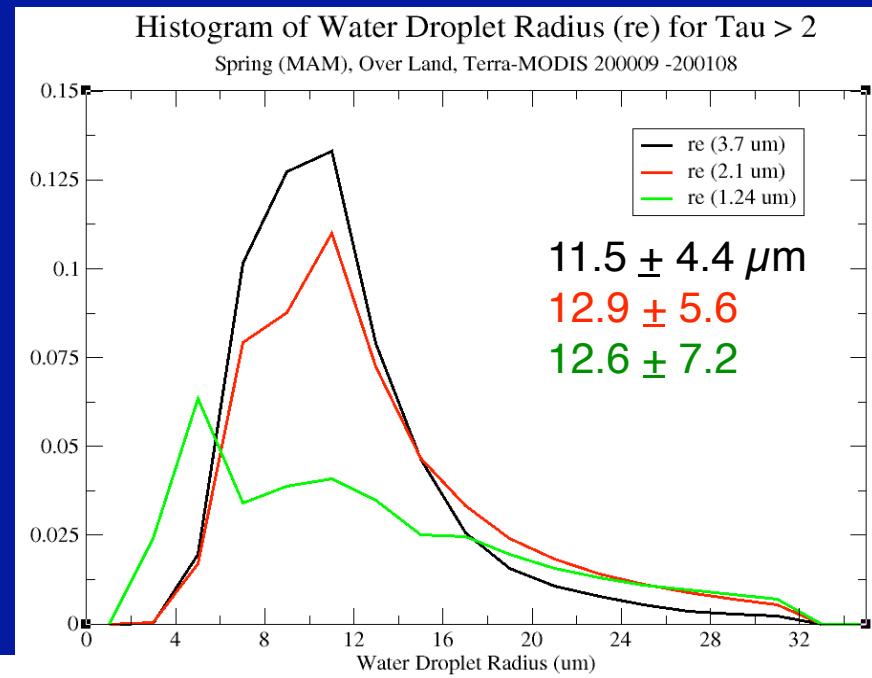


Spectral Ed4 Ice Crystal Re (μm)
Summer 2001, $\tau > 2$

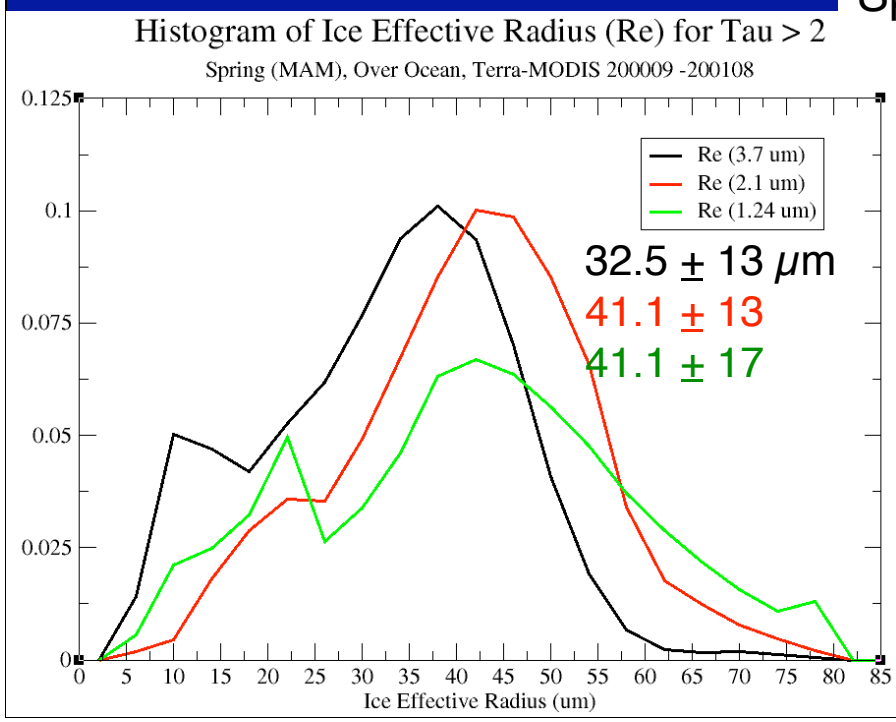
- greater variability in 1.2 ratio than in 2.1 ratio, for typical cirrus, Re(2.1) > Re(3.7), but R(1.2)?

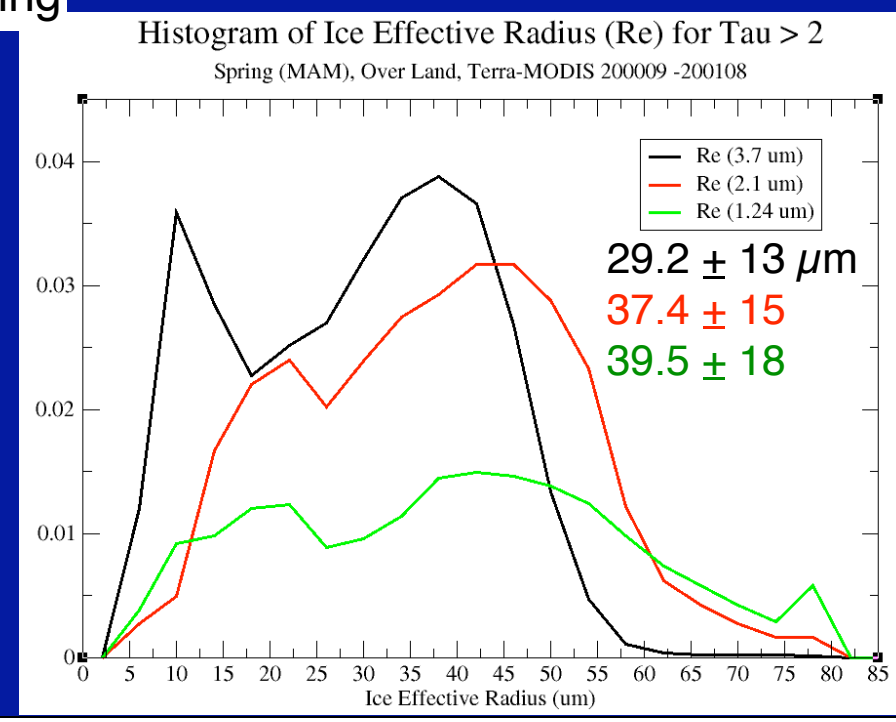


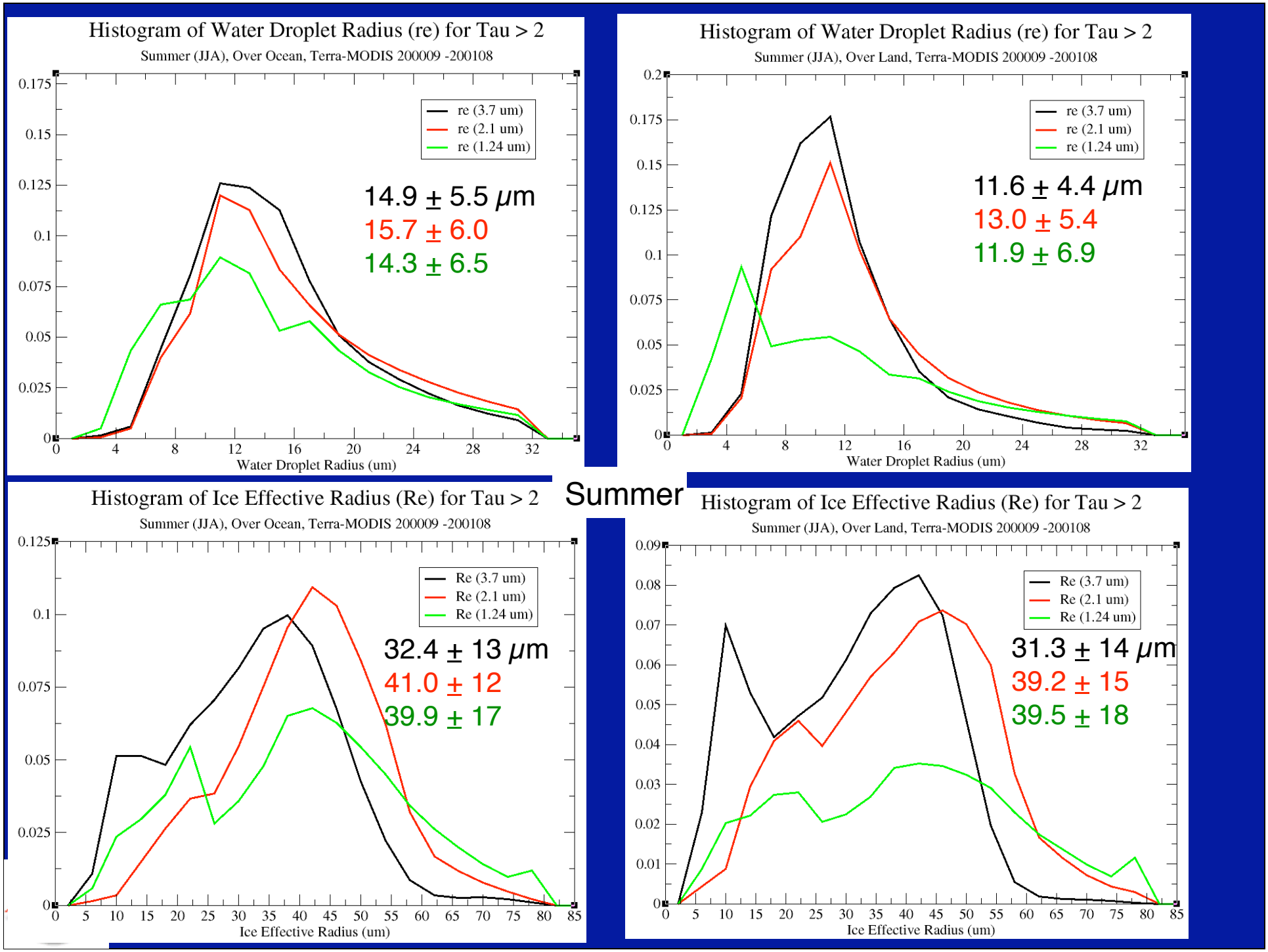

Histogram of Water Droplet Radius (re) for Tau > 2
Spring (MAM), Over Ocean, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
14.3 ± 5.2 μm
15.3 ± 6.0
14.8 ± 6.5
Water Droplet Radius (um)

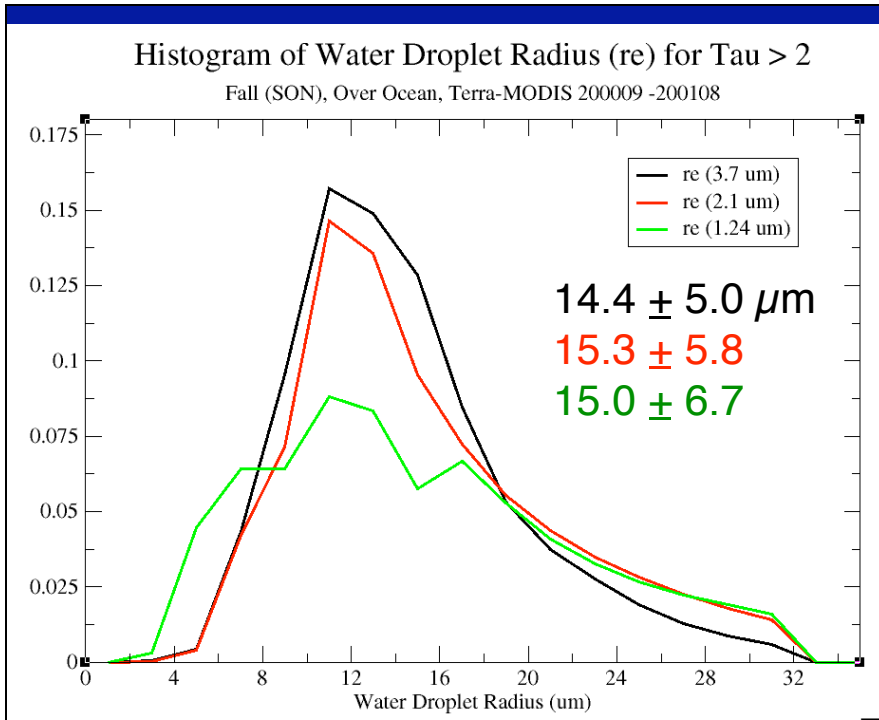

Histogram of Water Droplet Radius (re) for Tau > 2
Spring (MAM), Over Land, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
11.5 ± 4.4 μm
12.9 ± 5.6
12.6 ± 7.2
Water Droplet Radius (um)

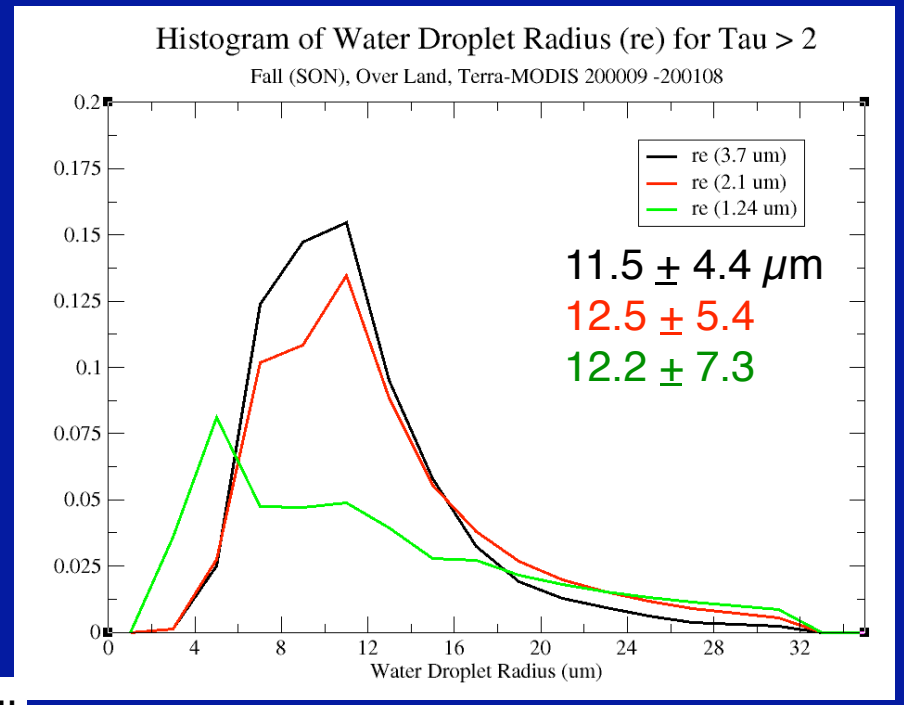
Spring


Histogram of Ice Effective Radius (Re) for Tau > 2
Spring (MAM), Over Ocean, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
32.5 ± 13 μm
41.1 ± 13
41.1 ± 17
Ice Effective Radius (um)

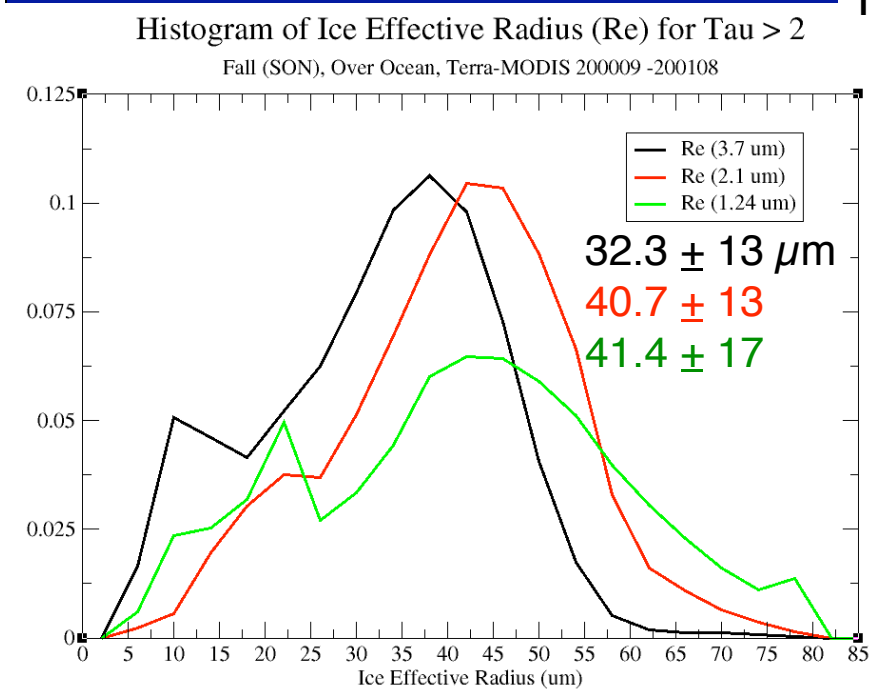

Histogram of Ice Effective Radius (Re) for Tau > 2
Spring (MAM), Over Land, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
29.2 ± 13 μm
37.4 ± 15
39.5 ± 18
Ice Effective Radius (um)

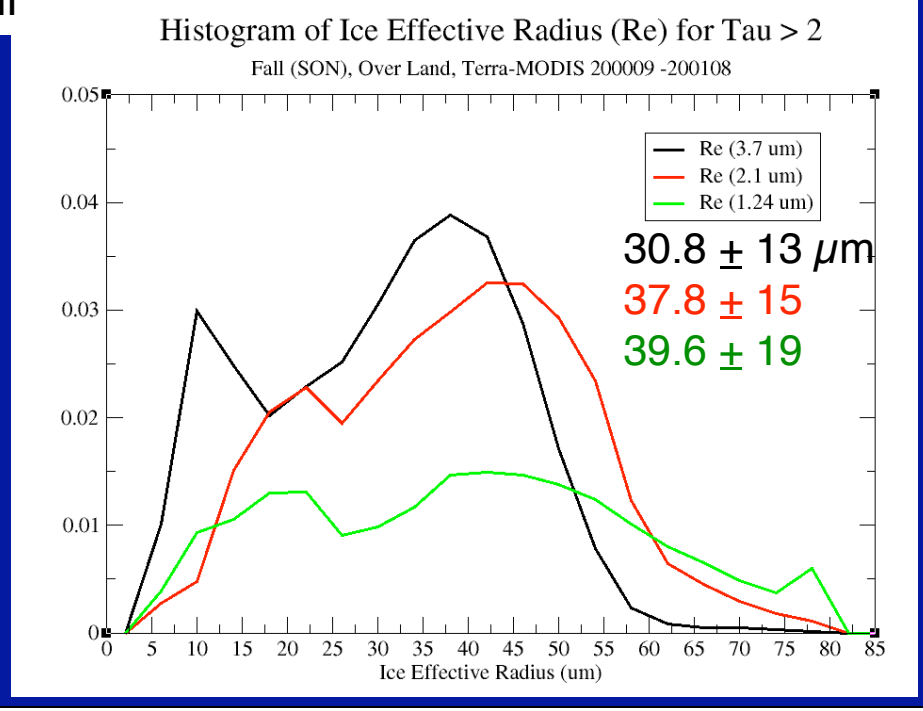

Histogram of Water Droplet Radius (re) for Tau > 2
Summer (JJA), Over Ocean, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
14.9 ± 5.5 μm
15.7 ± 6.0
14.3 ± 6.5
Water Droplet Radius (um)
Histogram of Water Droplet Radius (re) for Tau > 2
Summer (JJA), Over Land, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
11.6 ± 4.4 μm
13.0 ± 5.4
11.9 ± 6.9
Water Droplet Radius (um)
Summer
Histogram of Ice Effective Radius (Re) for Tau > 2
Summer (JJA), Over Ocean, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
32.4 ± 13 μm
41.0 ± 12
39.9 ± 17
Ice Effective Radius (um)
Histogram of Ice Effective Radius (Re) for Tau > 2
Summer (JJA), Over Land, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
31.3 ± 14 μm
39.2 ± 15
39.5 ± 18
Ice Effective Radius (um)

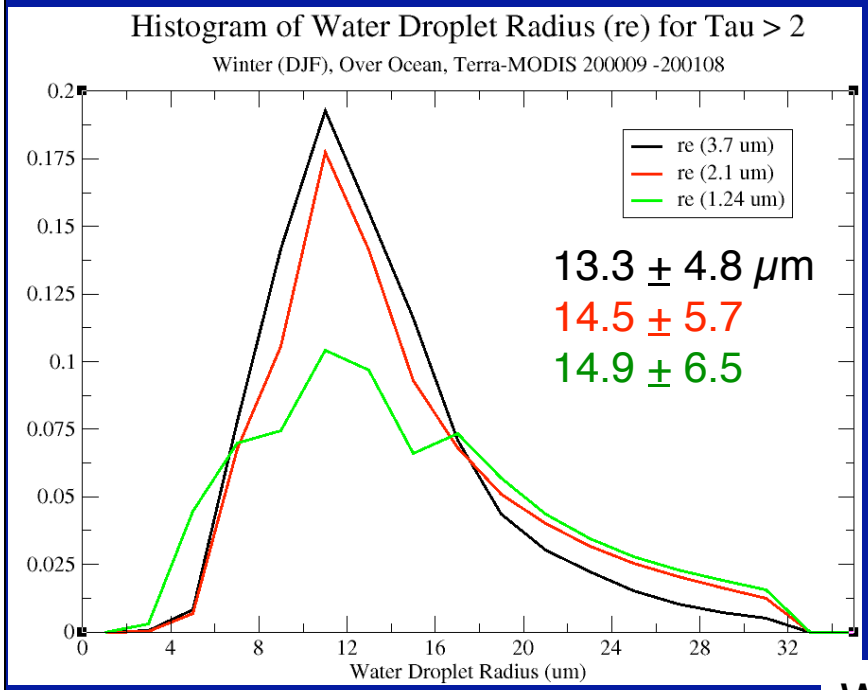

Histogram of Water Droplet Radius (re) for Tau > 2
Fall (SON), Over Ocean, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
14.4 ± 5.0 μm
15.3 ± 5.8
15.0 ± 6.7
Water Droplet Radius (um)

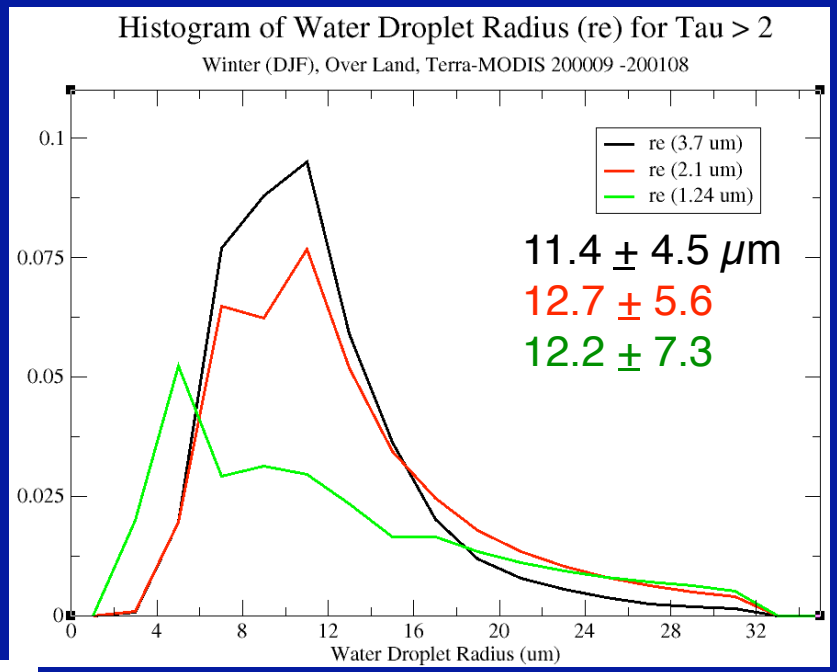

Histogram of Water Droplet Radius (re) for Tau > 2
Fall (SON), Over Land, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
11.5 ± 4.4 μm
12.5 ± 5.4
12.2 ± 7.3
Water Droplet Radius (um)

Fall

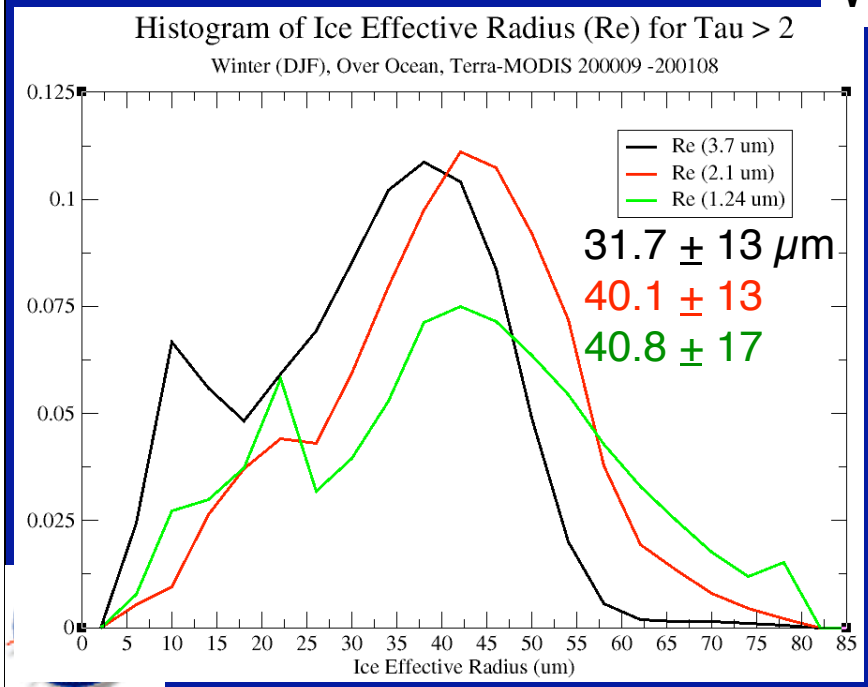

Histogram of Ice Effective Radius (Re) for Tau > 2
Fall (SON), Over Ocean, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
32.3 ± 13 μm
40.7 ± 13
41.4 ± 17
Ice Effective Radius (um)

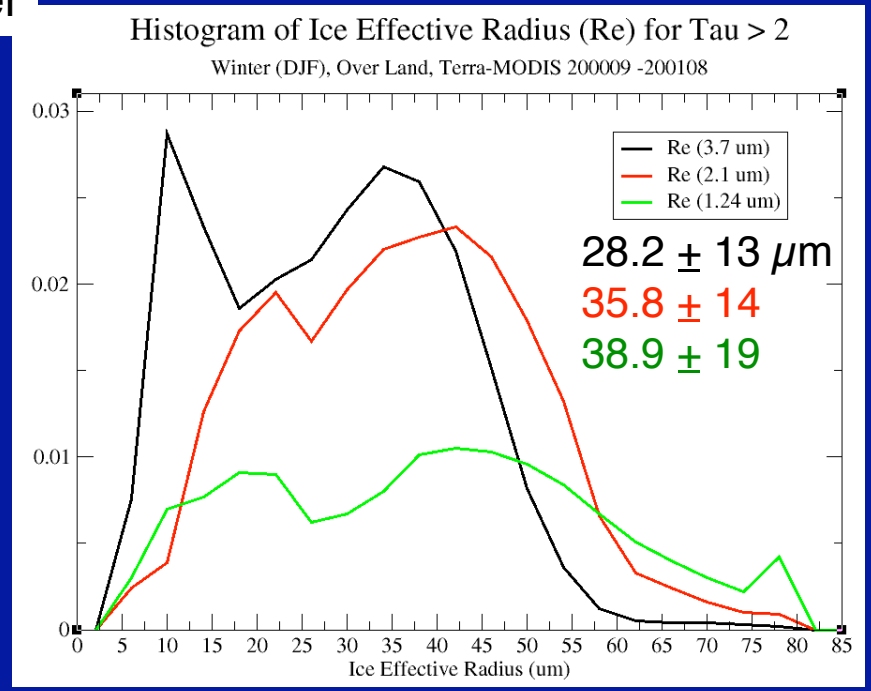

Histogram of Ice Effective Radius (Re) for Tau > 2
Fall (SON), Over Land, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
30.8 ± 13 μm
37.8 ± 15
39.6 ± 19
Ice Effective Radius (um)


Histogram of Water Droplet Radius (re) for Tau > 2
Winter (DJF), Over Ocean, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
13.3 ± 4.8 μm
14.5 ± 5.7
14.9 ± 6.5
Water Droplet Radius (um)

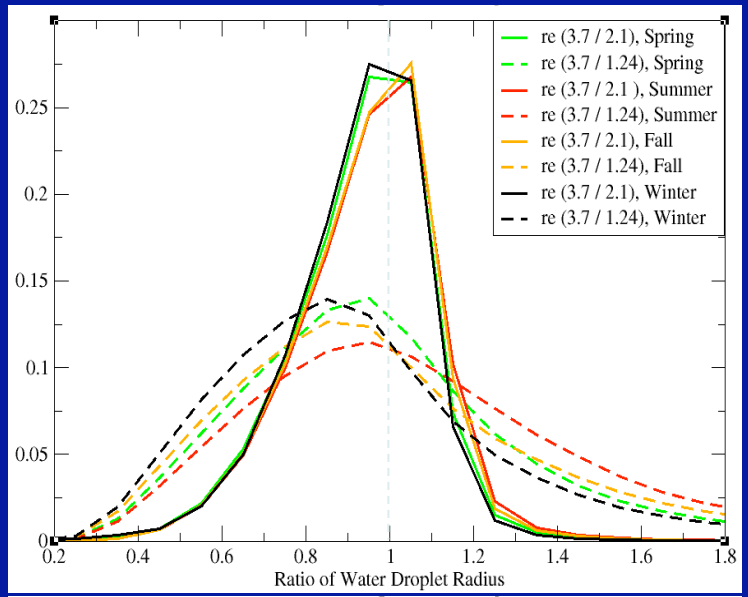

Histogram of Water Droplet Radius (re) for Tau > 2
Winter (DJF), Over Land, Terra-MODIS 200009 -200108
re (3.7 um)
re (2.1 um)
re (1.24 um)
11.4 ± 4.5 μm
12.7 ± 5.6
12.2 ± 7.3
Water Droplet Radius (um)

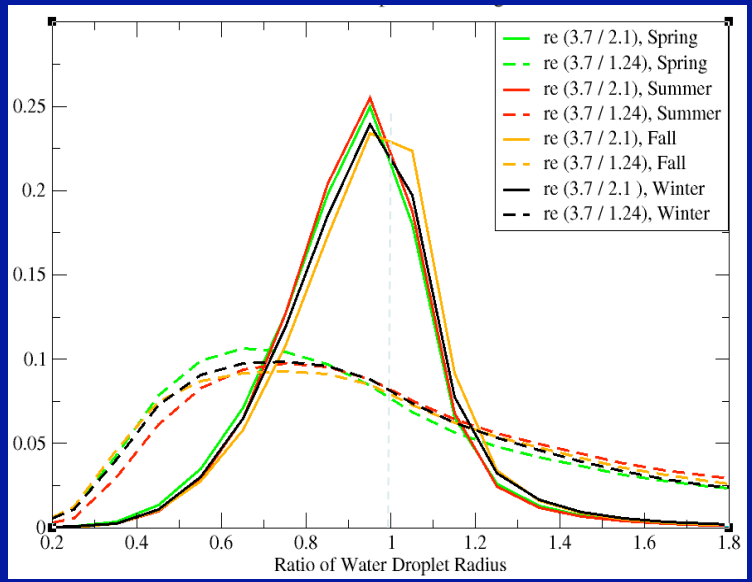
Winter

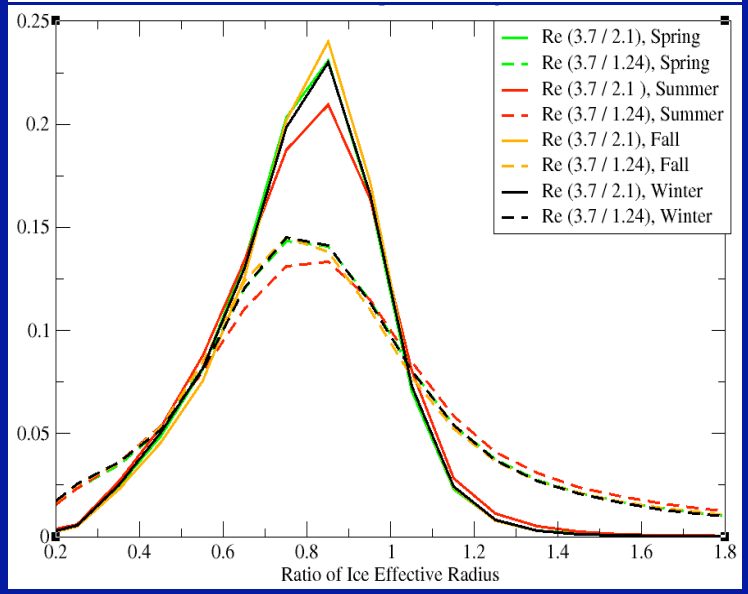

Histogram of Ice Effective Radius (Re) for Tau > 2
Winter (DJF), Over Ocean, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
31.7 ± 13 μm
40.1 ± 13
40.8 ± 17
Ice Effective Radius (um)

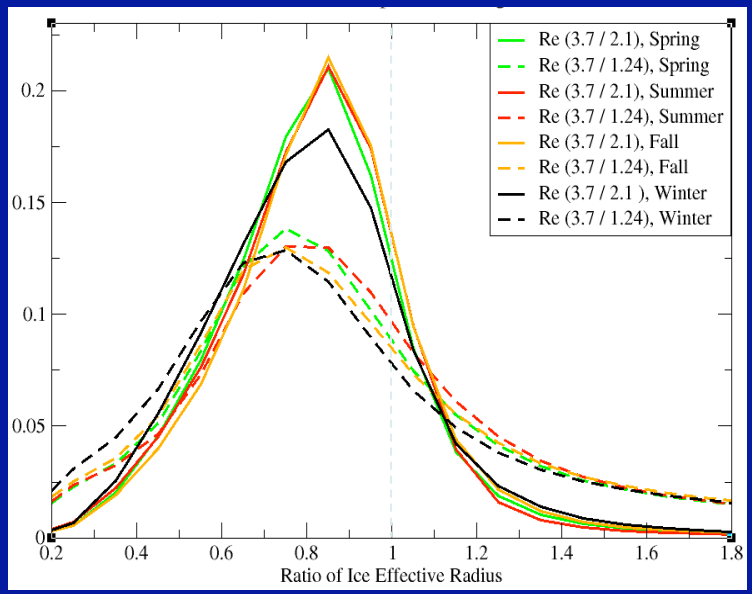

Histogram of Ice Effective Radius (Re) for Tau > 2
Winter (DJF), Over Land, Terra-MODIS 200009 -200108
Re (3.7 um)
Re (2.1 um)
Re (1.24 um)
28.2 ± 13 μm
35.8 ± 14
38.9 ± 19
Ice Effective Radius (um)

Ratios of Effective Droplet Re: Ed 4
Summer 2000/2001



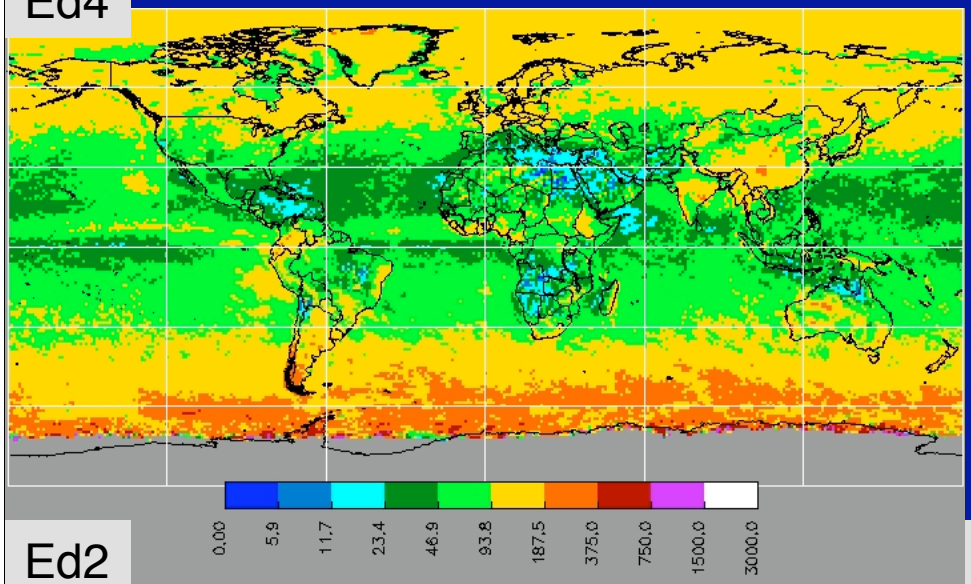




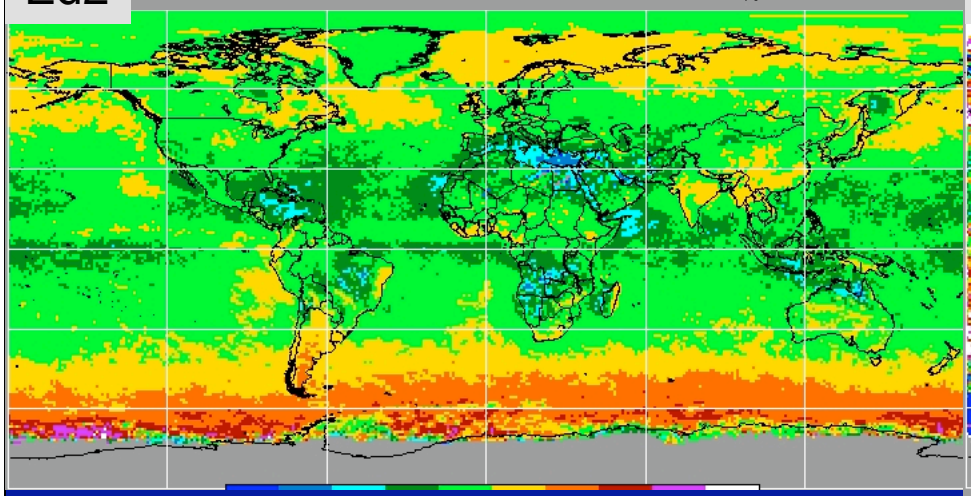


Daytime Cloud Liquid Water Path: Ed 2 versus Ed 4
Summer 2000/2001

Ed4

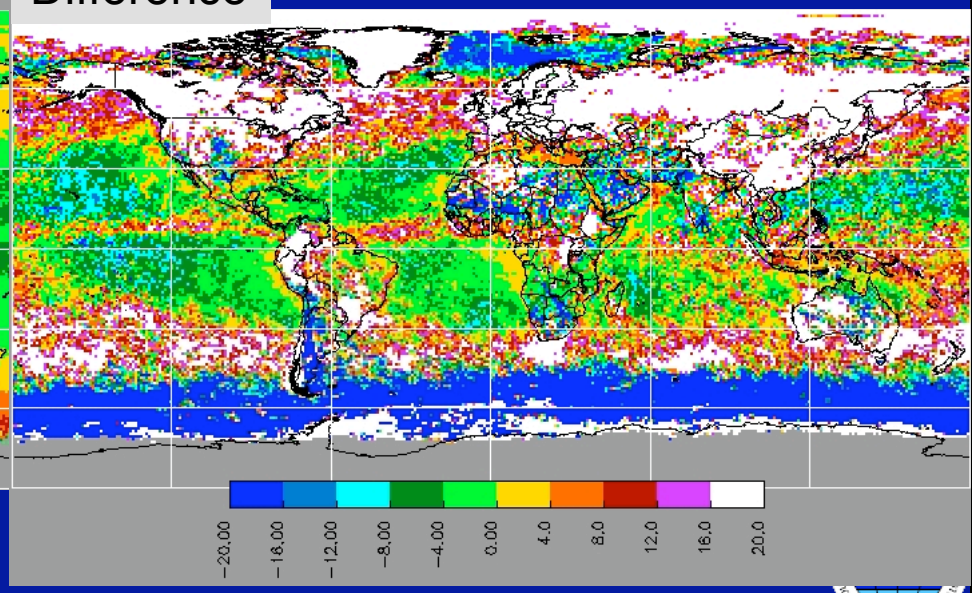


Ed2



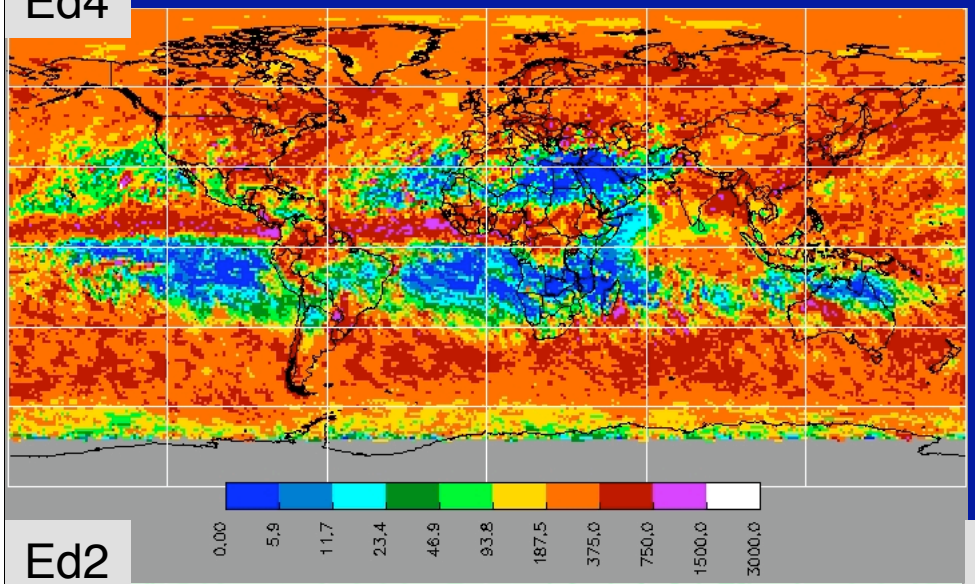
- Increases mostly follow τ increases
  - particularly in Arctic
- Decrease in southern midlatitudes due to drop in τ because of ozone
- Increase southern subtropics due to inclusion of former ice clouds

Difference

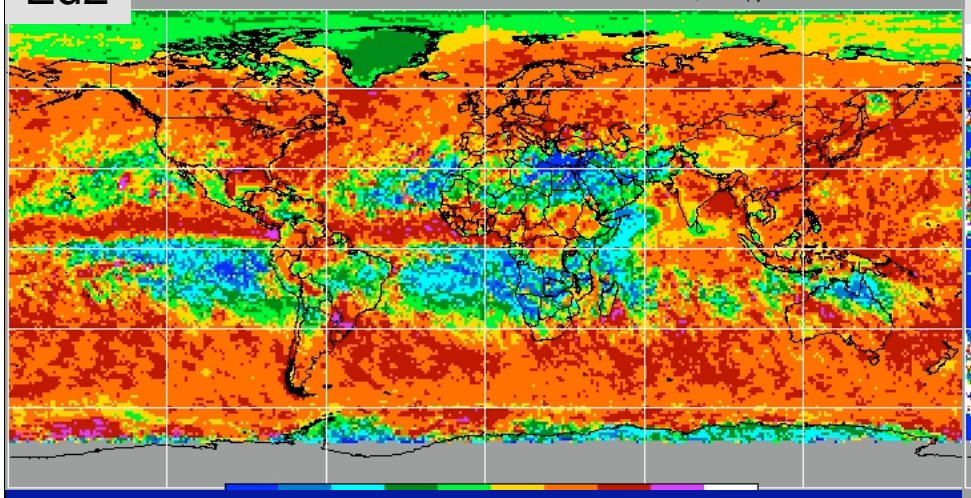


Daytime Cloud Ice Water Path: Ed 2 versus Ed 4
Summer 2000/2001

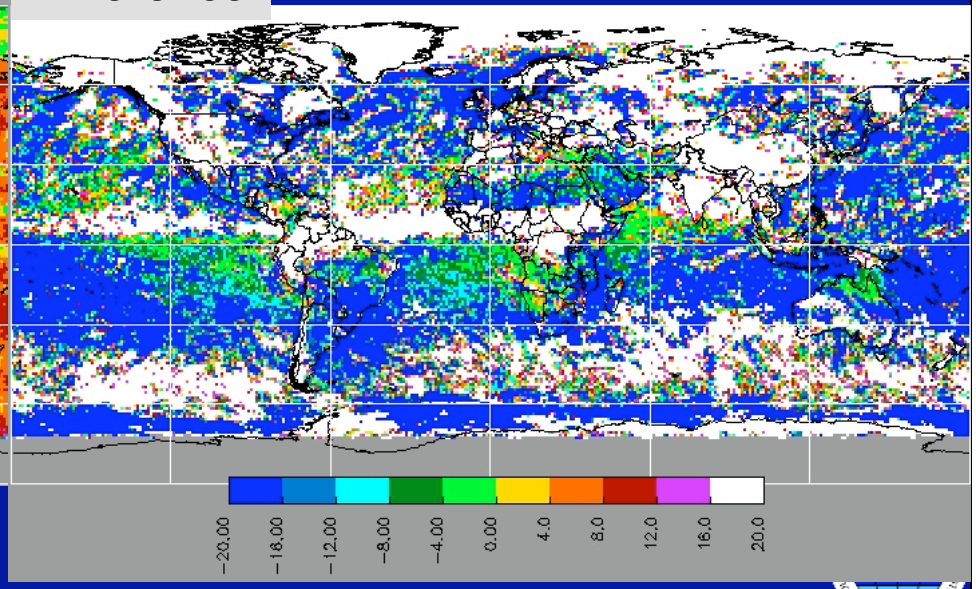
Ed4



Ed2

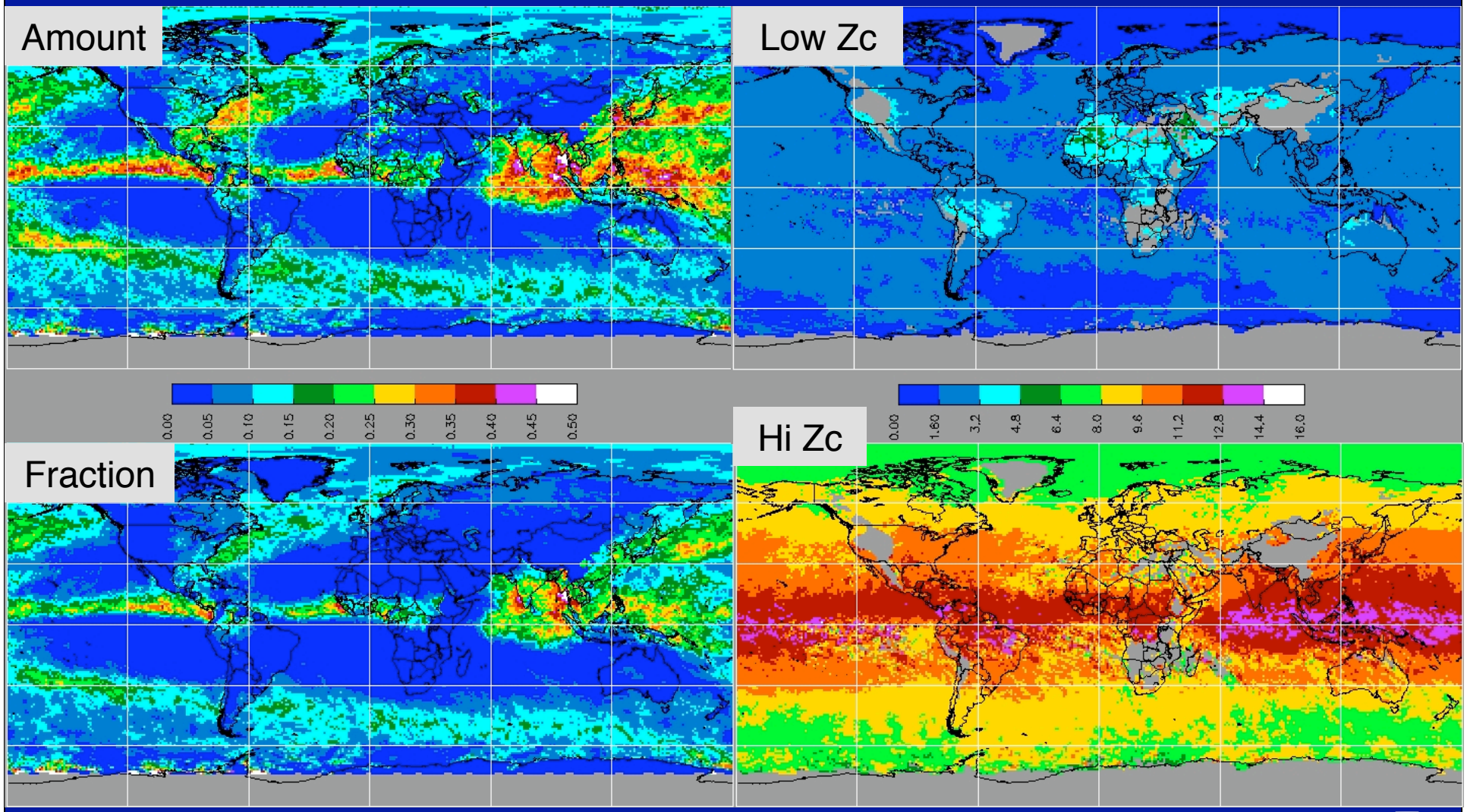


Difference



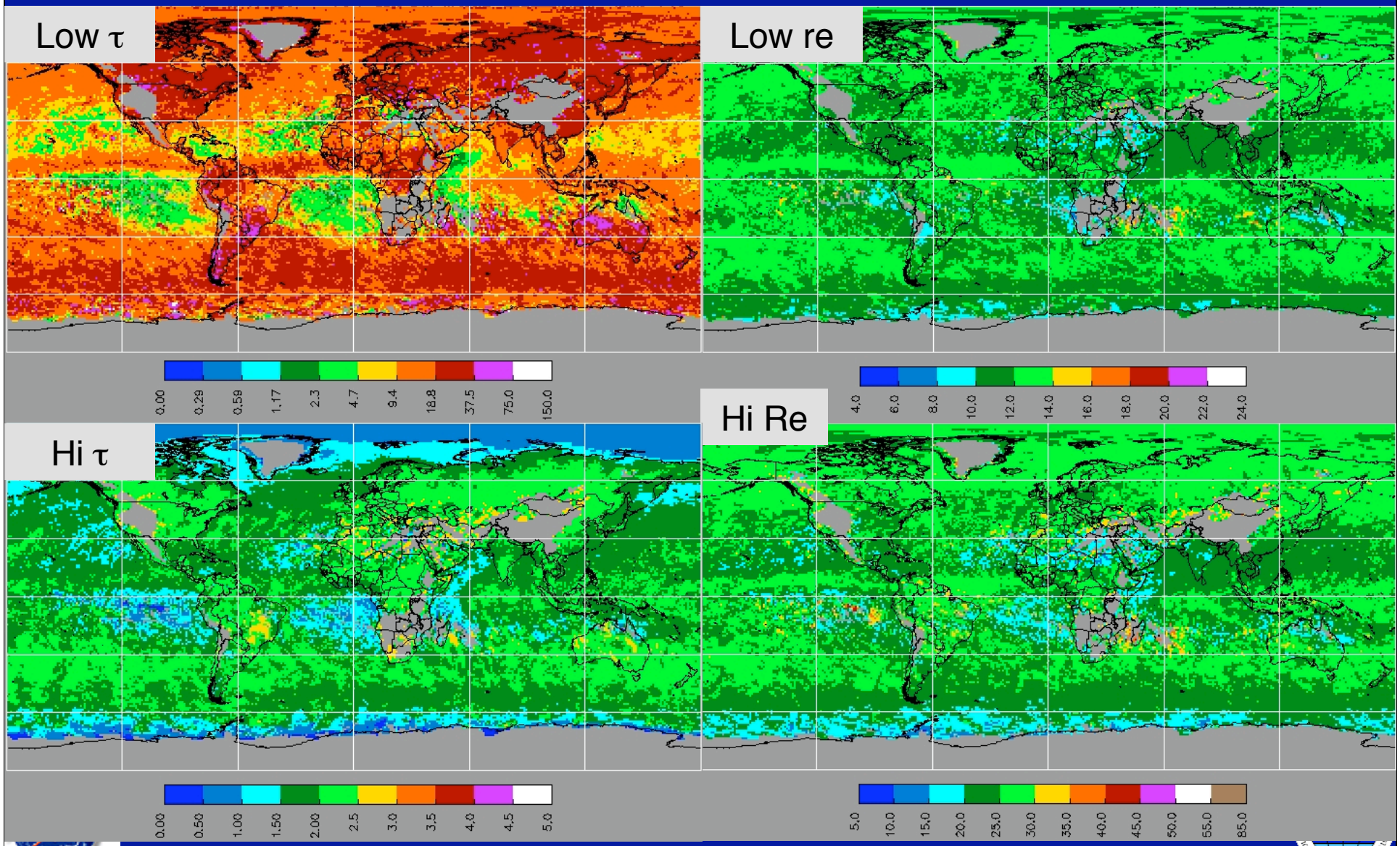
- Increases mostly follow τ increases
- Tropical decreases in Re enhance drop in IWP
- Arctic increases due to 1.24-μm τ

Daytime Multilayered Cloud Amounts & Heights
Summer 2000/2001



- 8% ML detected & retrieved, varies up to 9% with season

Daytime Multilayered Particle Size & Optical Depth
Summer 2000/2001

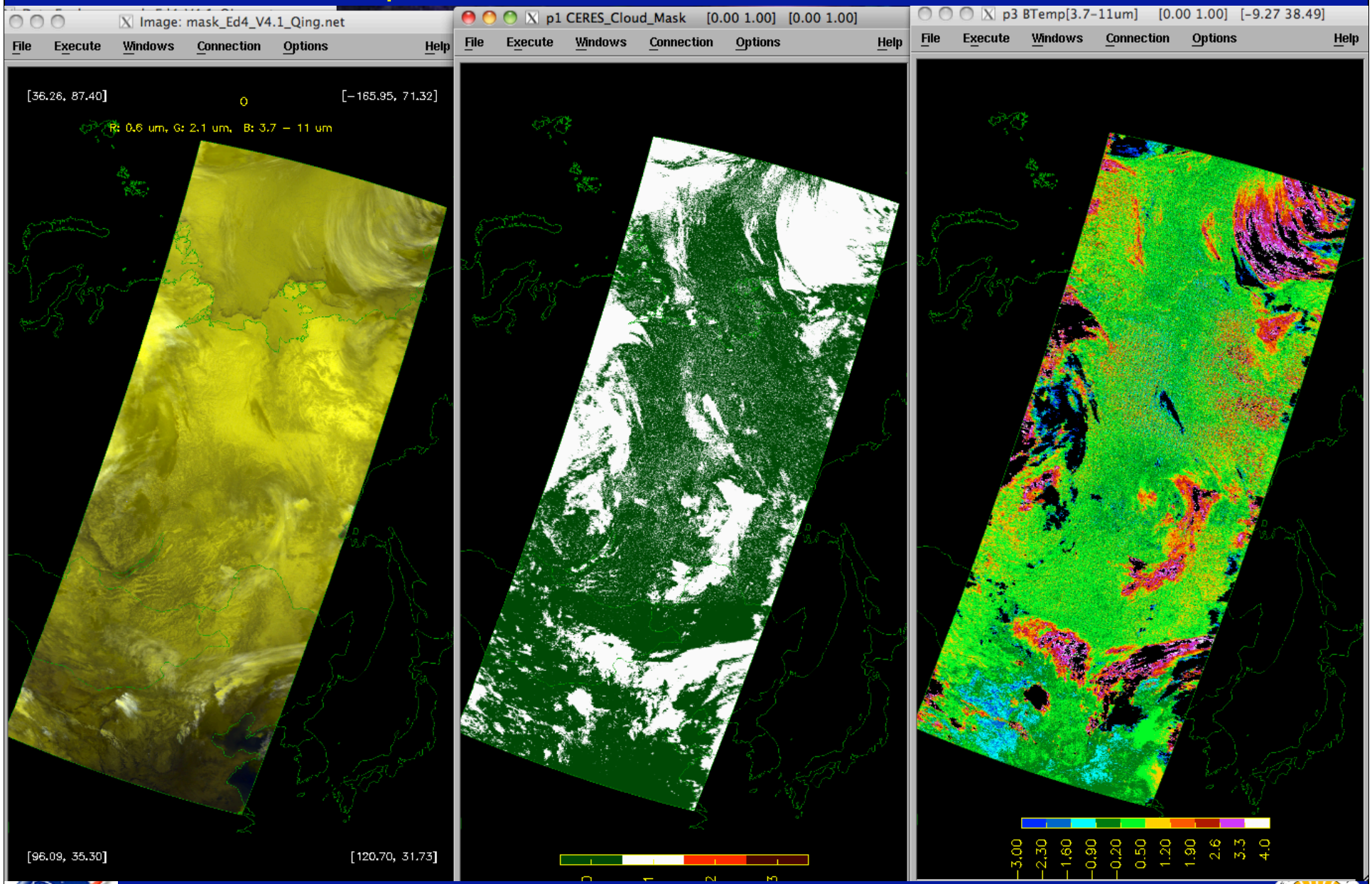


Bad News

- Ed4 was delivered too soon without thoroughly checking polar clouds
  - *focused on 2008*
  - *discontinuity line returned*
    - *small in daytime*
    - *significant at night*
  - *cloud fractions at night too high over polar regions*
    - *in some cases > CALIPSO*

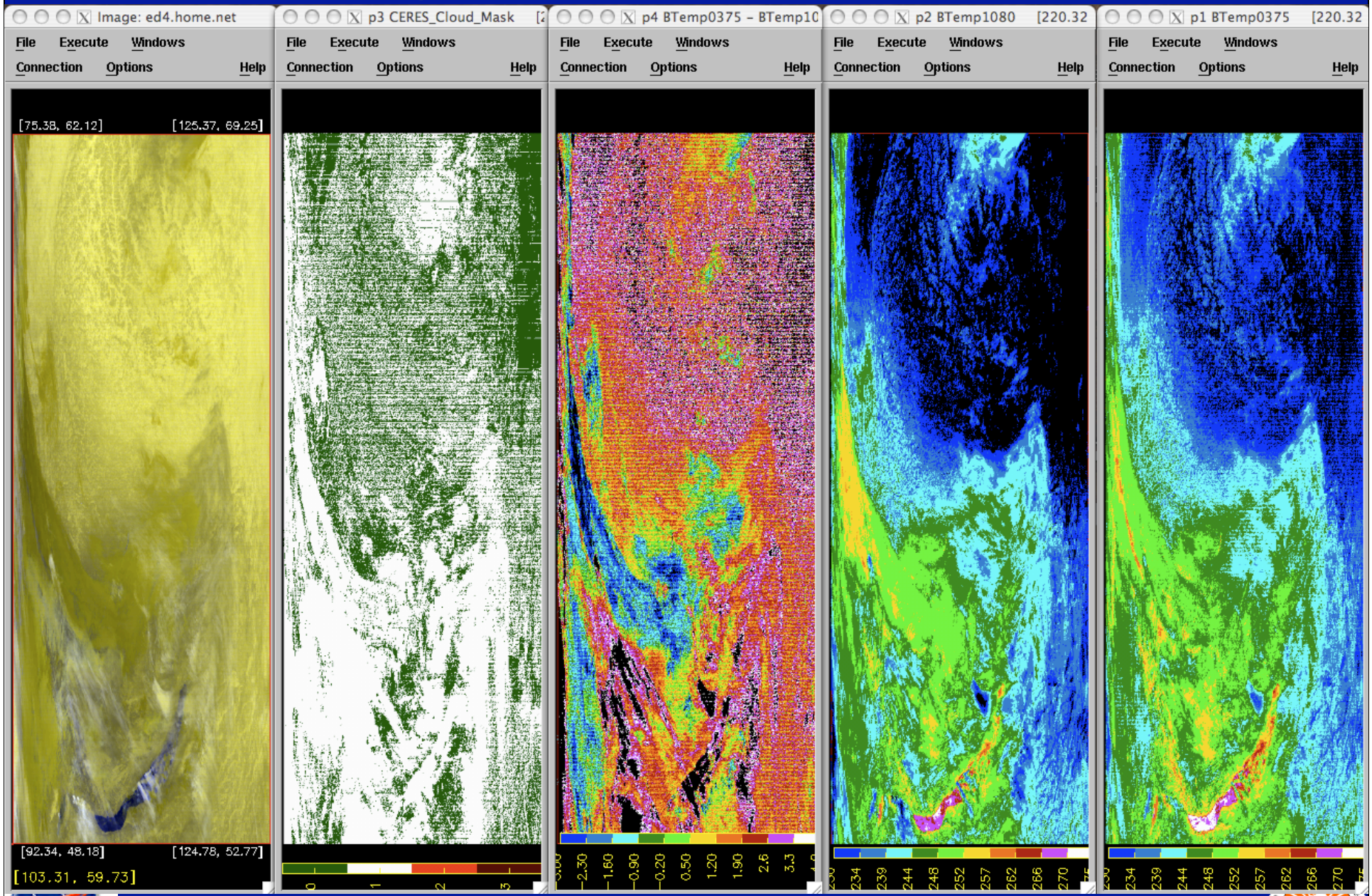
- Ed4a delivery proposed (Pre-Thanksgiving)
  - *address discontinuity & source of overestimation*
    - *BTD3.7-11 noise*
    - *T3.7 calibration*
    - *use of nonpolar mask for nonpermanent snow?*
  - *use data from early, mid, and late years*

Aqua Mask & BTD, Jan 15, 2003, Siberia



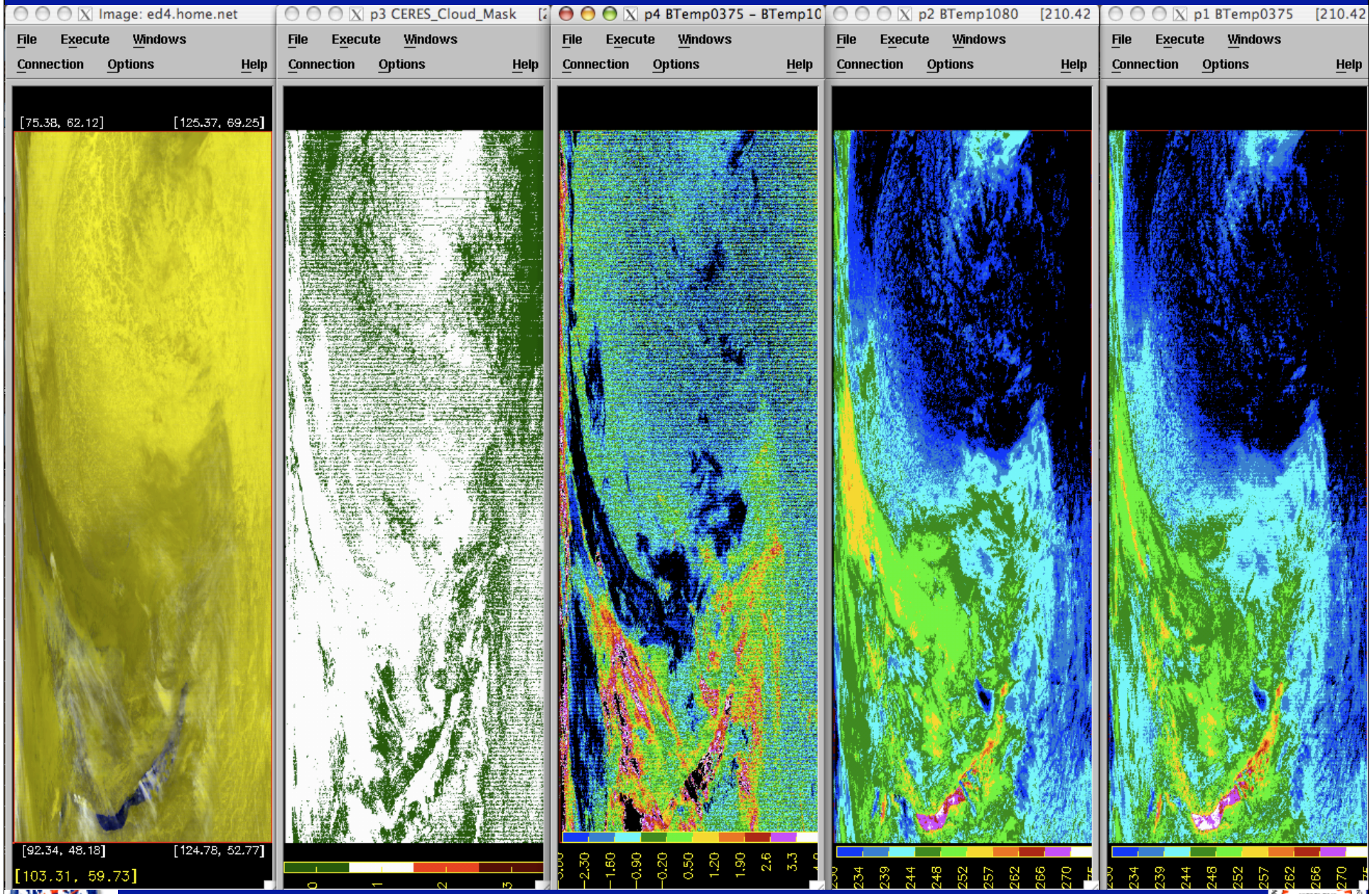
- Some noise, BTD near 0.3 for clear region

Terra Mask & Temperatures before Calibration, Dec 15, 2001, Siberia



- Very noisy at low temps, BTD > 3K for clear areas

Terra Mask & Temperatures after Calibration, Dec 15, 2001, Siberia



- Very noisy at low temps, BTD ~ -1.5 K for clear areas

Ed4 Cloud Properties on SSF

- All Ed2 parameters
- SSF-79, 79a: CWG Tskin, CWG PW
- SSF-94a, b: Cloud top temperature, height
- SSF 102a: Mean cloud base temperature
- SSF 108-110: re(1.6), Re(1.6), log[tau(1.6)]
- SSF 110a-c: re(2.1), Re(2.1), log[tau(2.1)]
- SSF 111: CO2 layer coverage
- SSF 111a-c: emissivity, pc, Tc for CO2
- SSF 112: CO2 Zc
- SSF 114a-l: multilayer, single-layer properties (n x 4)

  coverage, OD, log(OD), emissivity, pt, Tt, Zt
  Rere(3.7), re(3.7), Re(3.7)
  Rere(2.1), re(2.1), Re(2.1)

Future Plans

- Re-deliver Ed4a

- Continue preparation of code for NPP
  - look at other multilayer techniques
  - examine impact of losing CO2 and WV channels
  - develop cloud absorptance/reflectance models for 2.25 μm channel

- Monitor quality of Ed4a results

- Pursue validation of Ed4a results

- Document Ed4a algorithms & initial results

- Continue retrieval research