The Flux-by-cloud type simulator

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SSAI

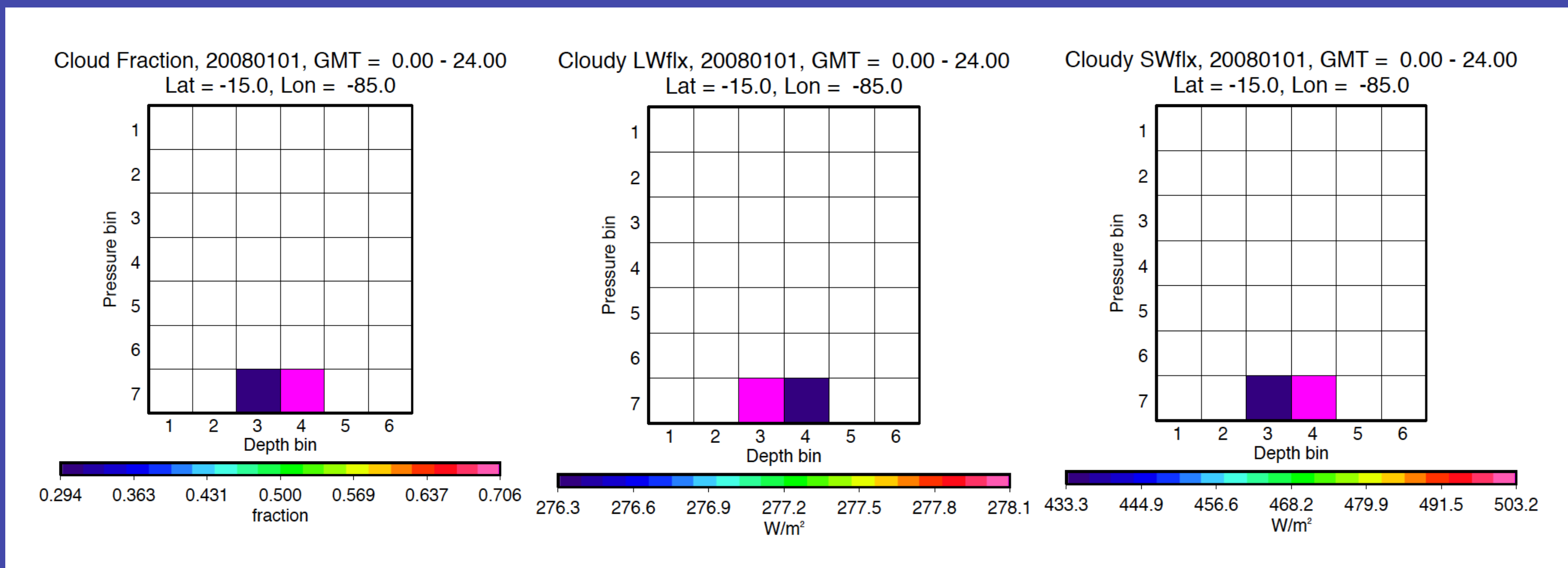
Thanks to Norman Loeb, Kuan-Man Xu, Wenying Su, David Doelling, Moguo Sun, Noel Baker, and Dennis Keyes!

What is the Flux-by-cloud type product?

- Assigns a flux to each observed ISCCP cloud type within a region.
- For each 1°x1° region between 60° S and 60° N, each daytime footprint is placed into 1-3 p_c-τ ISCCP-like categories (3 categories would be the case of a footprint with two cloud levels as well as clear pixels).
- For the footprints with a single cloud type, the standard SSF flux is added to that p_c-τ category.
- For footprints with multiple cloud levels, narrowband-to-broadband radiance conversions are performed for each cloud level.
- Broadband radiances are converted to fluxes using ADMs.

Sample Flux-by-cloud type plots

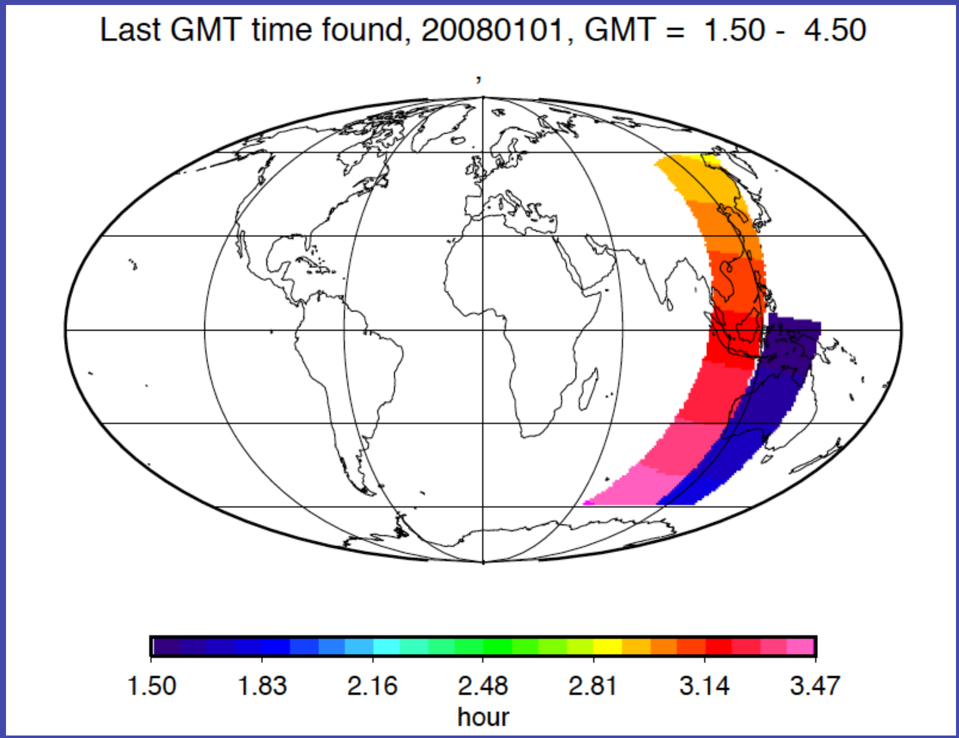
Cloud fraction | LW flux | SW flux



Here, Terra passed over the SE Pacific on Jan 1 2008, and there were two p_c-τ cloud types (p_c=800-1000 hPa, τ=3.6-9.4 and τ=9.4-23). The optically thicker part of the region has more outgoing SW, and slightly less OLR.

What is a simulator?

- Put simply, a simulator is meant to replicate what a space-based instrument would measure if it flew above a GCM or other model on the temporal and spatial scales of the measurements.



Motivation for flux-by-cloud type simulator

- Cloud properties and fluxes/albedos are matched within 1.5 hours to the closest CERES overpass, which is important because of the large diurnal cycles in cloud fraction, τ, and p_c in many areas.
- Breaking out the flux by cloud type can help isolate physical parameterizations that are problematic (e.g., convective clouds, boundary-layer parameterizations, or processes involving surface albedo), and provide a test for new parameterizations.
- Diagnoses using flux-by-cloud type combined with frequency of occurrence can also help determine whether an unrealistically small or large occurrence of a given cloud type has an important radiative impact for a given region.

Outline of Simulator Approach

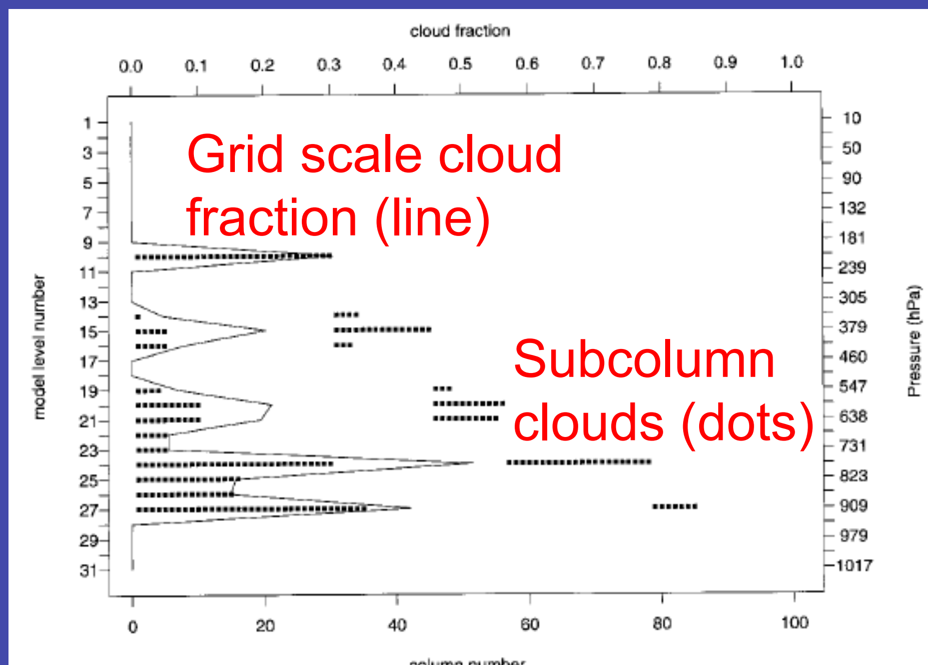
1. Read in data at GCM grid size
2. Run cloud generator and cloud property simulator to produce atmospheric subcolumns
3. Classify subcolumns into p_c-τ cloud types
4. Perform radiative transfer on a subset of subcolumns in each type

Cloud Generator

•GCM grid cells are much larger (~1°×1°, or ~10000 km^2) than MODIS pixels (~8 km^2 spacing), so the grid cells are first split into enough "pseudo-pixel" subcolumns so that they represent a comparable area.

•The subcolumns are assigned a binary (0 or 1) cloud fraction at each vertical level using a cloud generator (Klein and Jakob 1999; Webb et al. 2001) with the maximum-random overlap assumption.

Model level/p_c



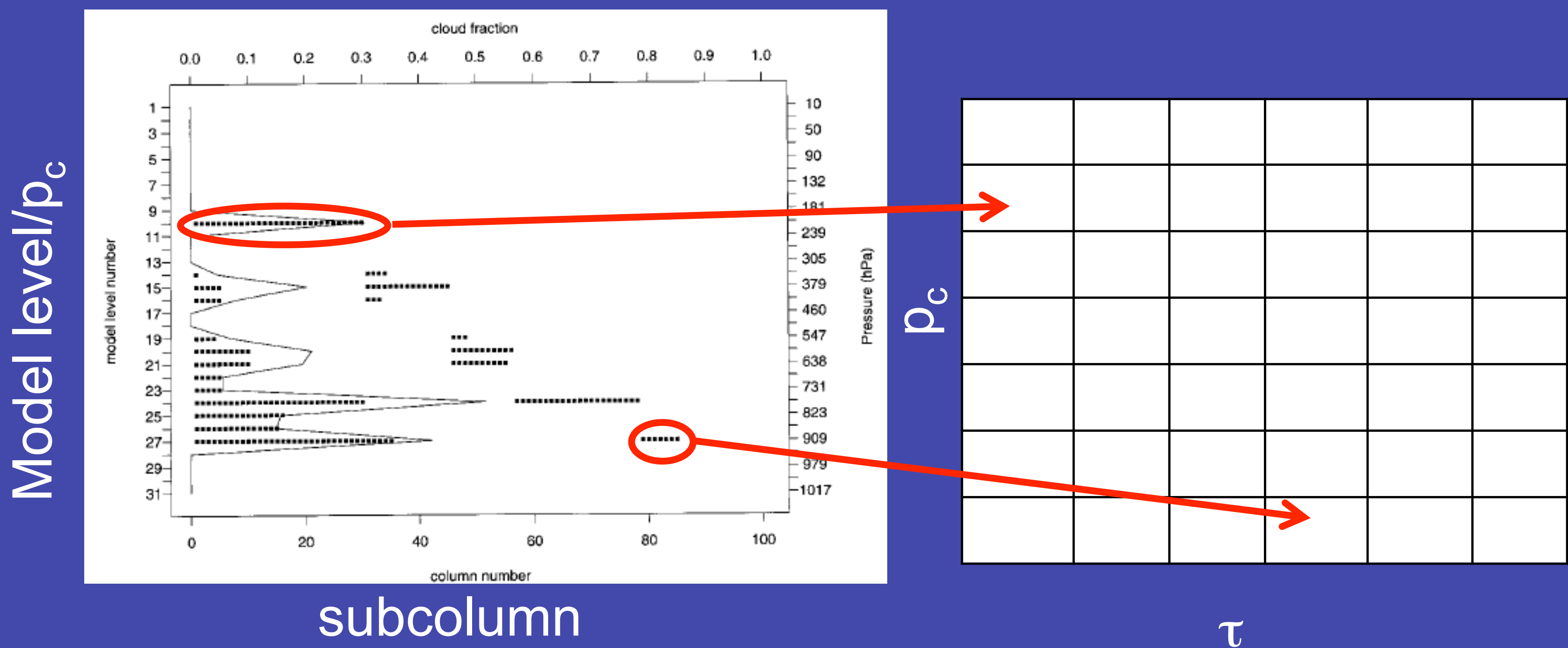
subcolumn

Figure from Klein and Jakob 1999

Cloud Property Simulator

•The MODIS simulator from the CFMIP Observational Simulator Package (COSP) is used to derive cloud properties.

•Each cloudy subcolumn is assigned to one of the 42 p_c-τ cloud types based on the p_c and τ values obtained from the MODIS simulator, with clear columns representing a 43rd type.

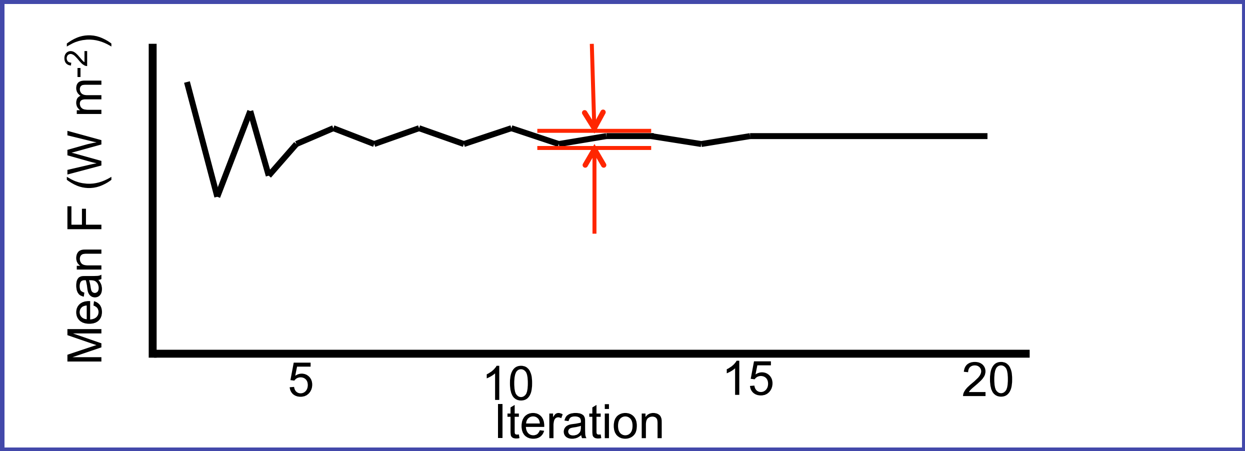


Langley Fu-Liou Model

•Fu-Liou radiative transfer model is run for at least 5 profiles for each p_c-τ cloud type, obtaining mean broadband LW and SW fluxes, $F_{LW}(5)$, $F_{SW}(5)$.

•Meteorological conditions (temperature, ozone concentration, water vapor mixing ratio, surface albedo, solar zenith angle) are considered horizontally homogeneous over each GCM grid cell.

•Computationally expensive to calculate radiative transfer on every column, so it is performed on additional profiles until mean flux F(n+1) does not change much relative to F(n).



Future Work

- Apply simulator to models with 3-hourly IPCC CFMIP (Cloud Feedback Model Intercomparison Project) output.
- We will compare flux-by-cloud type output on monthly or greater timescales, since fluctuations associated with weather are impossible for climate models to reproduce.
- Use albedo rather than flux for SW because up to 1.5 hours of temporal mismatch will cause significant flux differences.
- Will run the simulator a limited number of times with radiative transfer applied to all subcolumns in order to verify that the limited number used will be a good approximation.

Extra slides

CERES Footprint

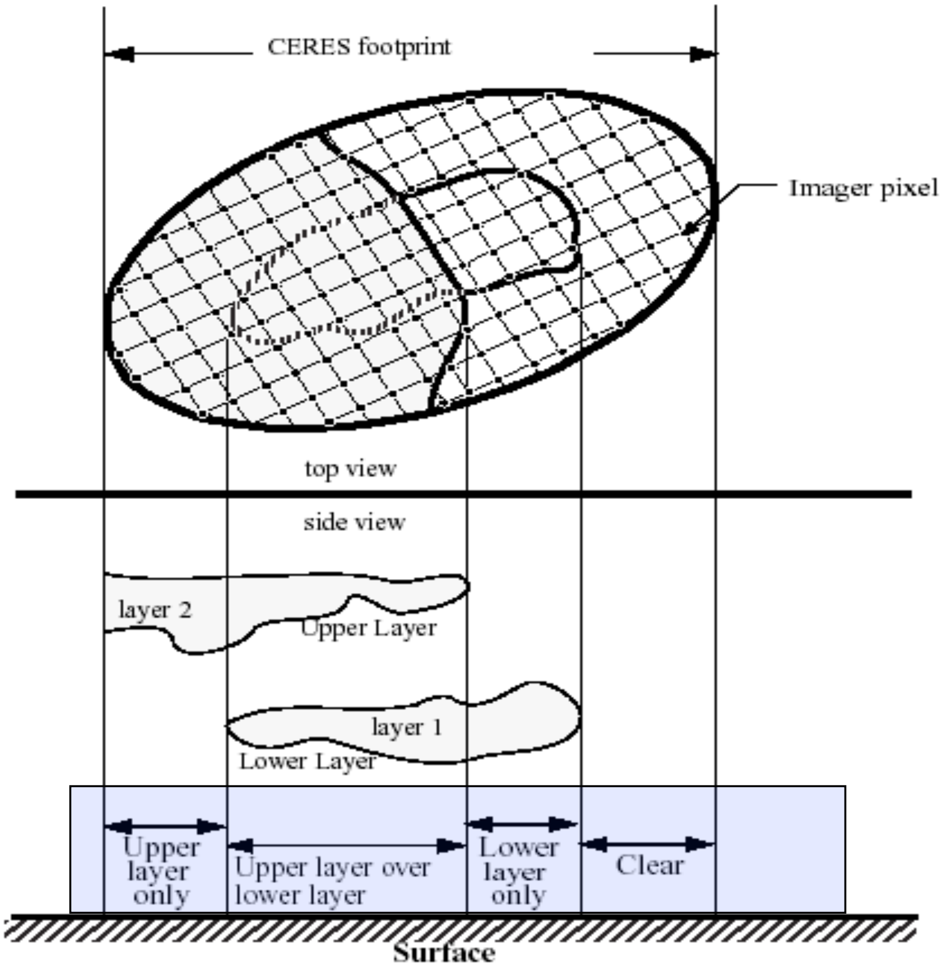


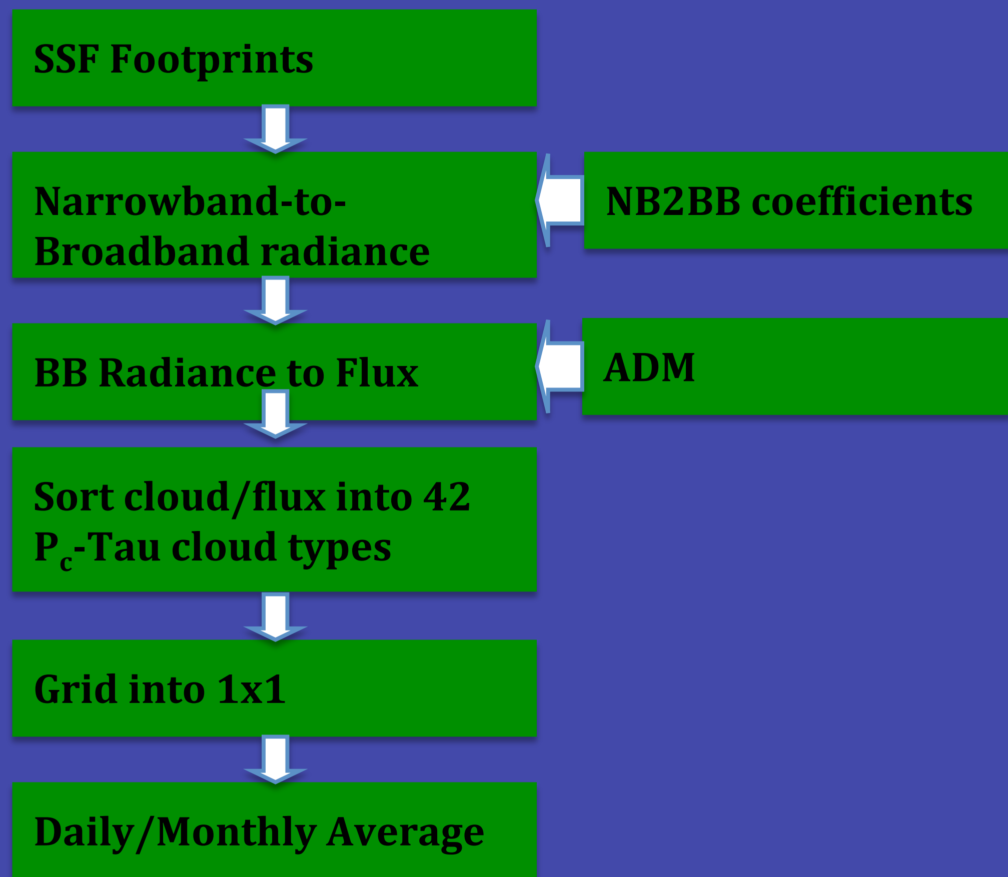
Figure 4-10. CERES Clear/layer/overlap illustration

3 parts but one total flux for a footprint:

- Upper layer
- Lower layer
- Clear

After processing, we will assign a flux value to each part.

Flux-by-cloud type Conceptual Flowchart



Narrowband to Broadband Radiance

- Bins based on SSF footprints monthly, daytime only
  - **LW: 11µm**

    7 VZA (every 10 deg, 0-70)

    4 PW (0.0,1.0,3.0,5.0,10.0)

    6 surface types: ocean, Forest, Savanna, Grass/Cropland, Dark Desert, Bright Desert.

    Excludes snow/ice surface type

    Require uniform surface within the Footprint.

    clear/overcast (100%)
  - **SW: 0.65µm, 1.64µm, 0.86µm**

    SZA(9), VZA(7), RAZ(9), Surface(6)

    clear/overcast (100%)

Broadband Radiance to Flux

- Logical Tree
  daytime SZA < 82°
  clear: cldf ≤ 0.1%, use original SSF flux
  cloudy: 0.1% < cldf < 99.9%, use ADM (input 100% cloud)
  clear/layer 1
  clear/layer 1/layer 2
  overcast: cld ≥ 99.9%,
  1 layer only, use original SSF flux
  2 layers, use ADM

  ADM is the ADM for Terra/Aqua. Loeb et al. JAOT, 2005

Broadband Radiance to Flux

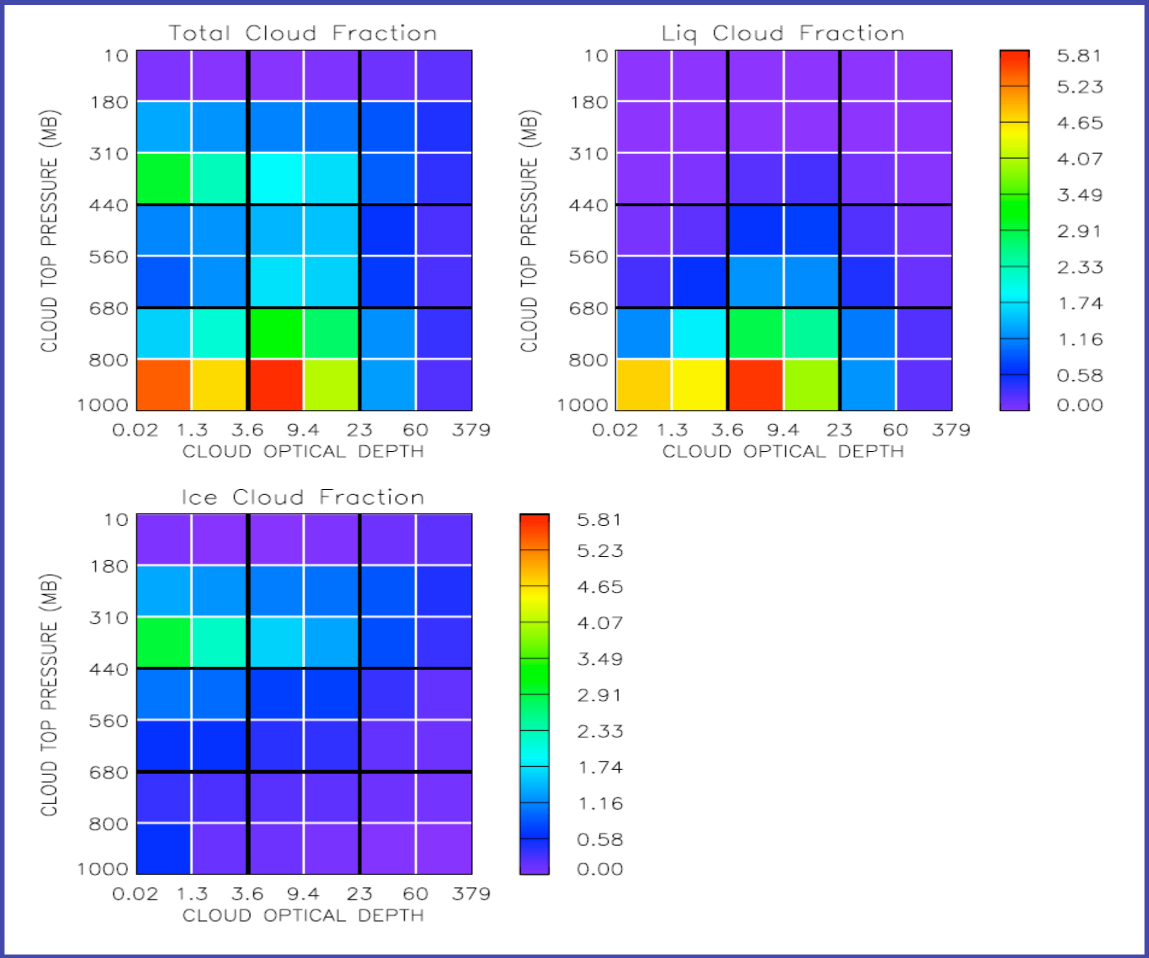
- Exclude glint, snow/ice, partial ocean, costal region
- Include non-uniform land surface dominant type
- Constraint: the sum of all three available parts equal SSF original flux
  - ✓ Weighted trust: derived flux has decreasing trustworthiness

    clear, layer1, layer2

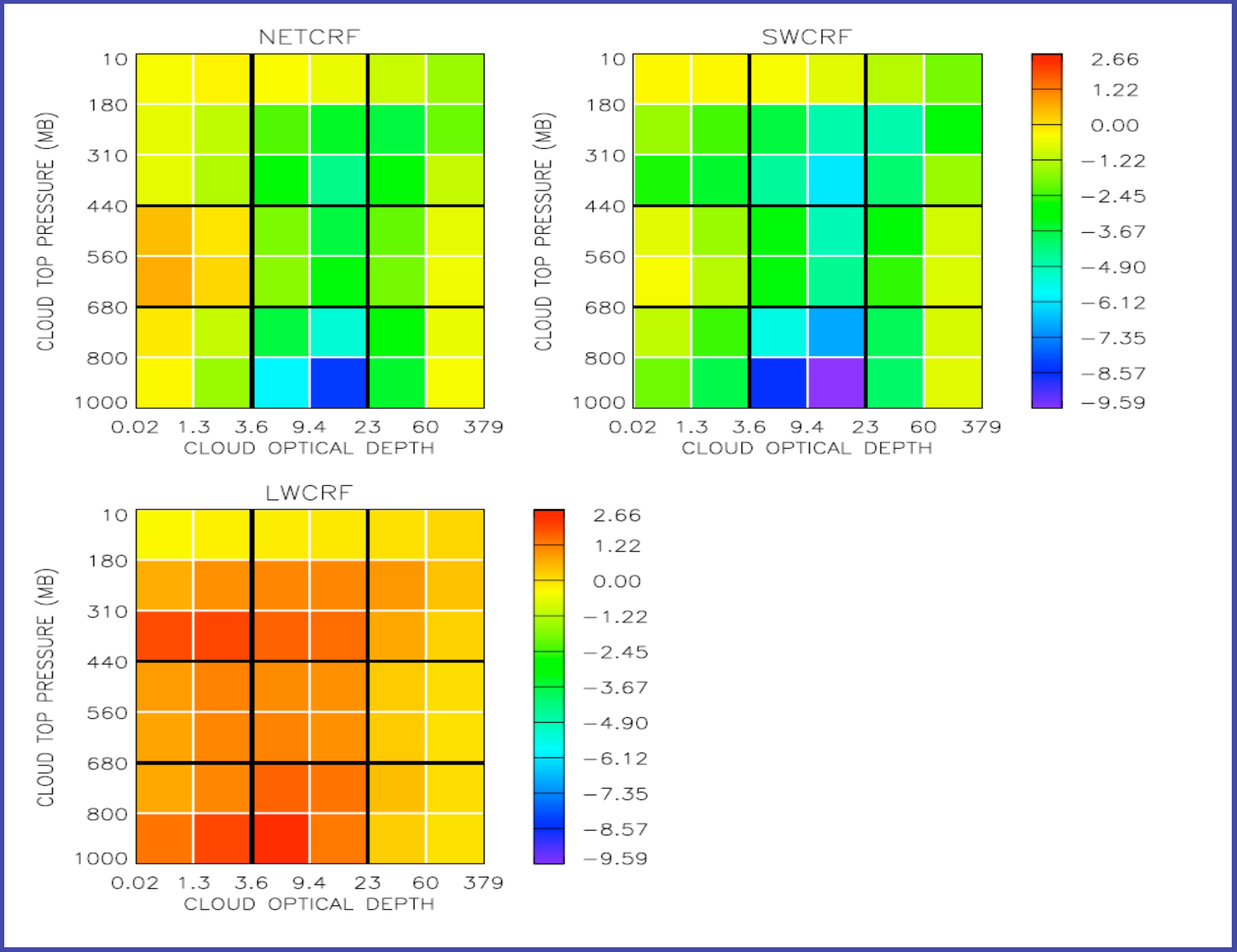
    if only clear and layer1, take derived clear flux as truth and only adjust layer1 value based on above constraint

    other cases have similar logic
  - ✓ Equal trust: Divide each derived flux by $Total_{ori}/Total_{new}$

Preliminary Results : Cloud Fraction by type, Terra Day Dec 2002



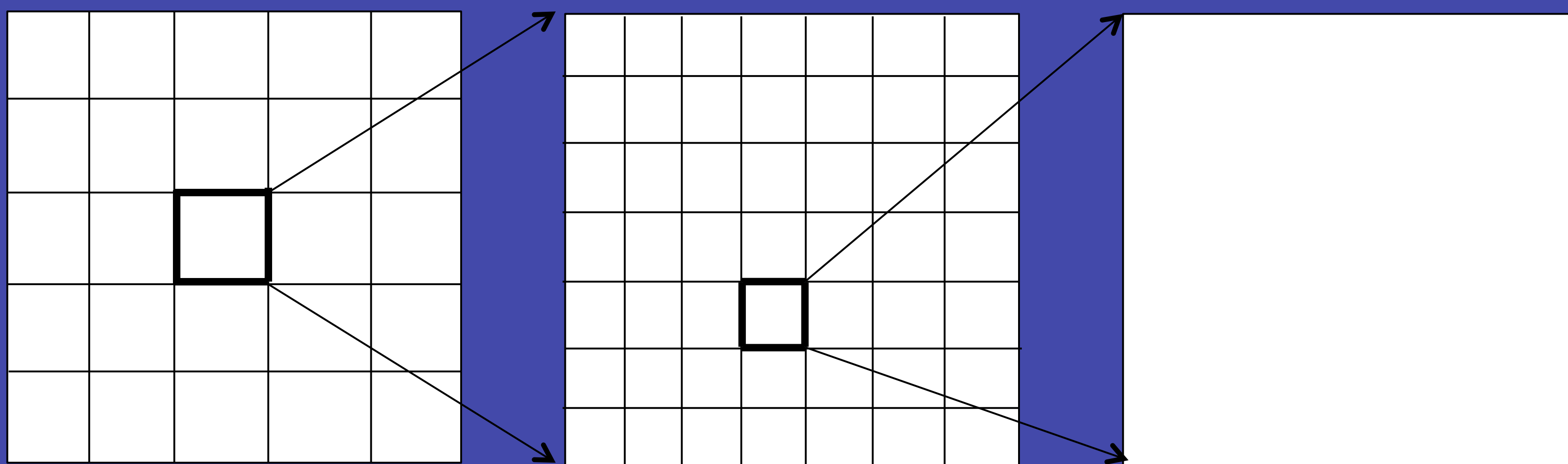
Preliminary Results : Flux by cloud type, Terra Day Dec 2002



Steps involved with offline Flux-by-cloud type Simulator

- Read in required variables: profiles of temperature, water vapor, cloud fraction, etc.
- For those grid cells that match the FBCT product (daytime, 60°S-60°N, closest model output time to Terra/Aqua overpass), use MODIS cloud property simulator at fine (~8km^2) resolution to produce ~1000 cloudy columns.
- These columns are grouped into p_c-τ categories.

Three separate scales

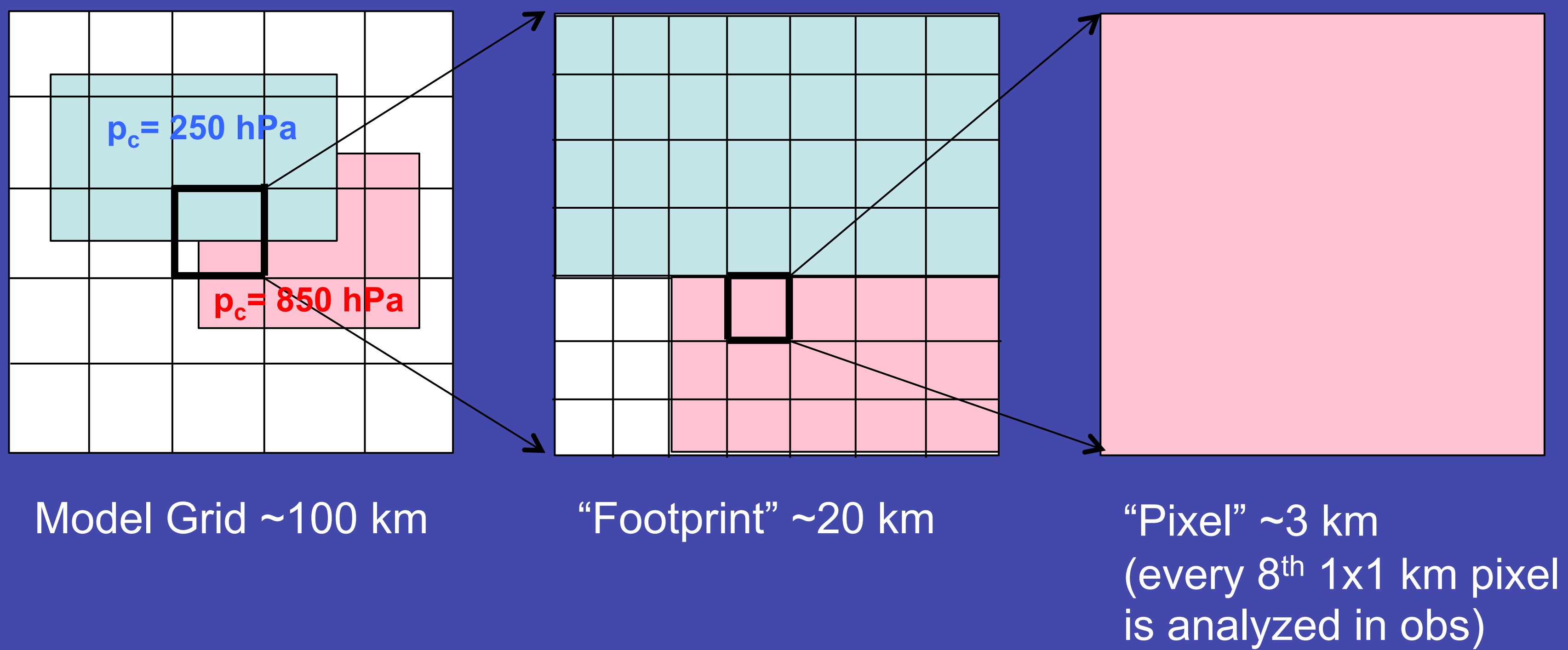


Model Grid ~100 km

“Footprint” ~20 km

“Pixel” ~3 km
(every 8th 1x1 km
pixel is analyzed)

Example with two clouds inside model grid cell



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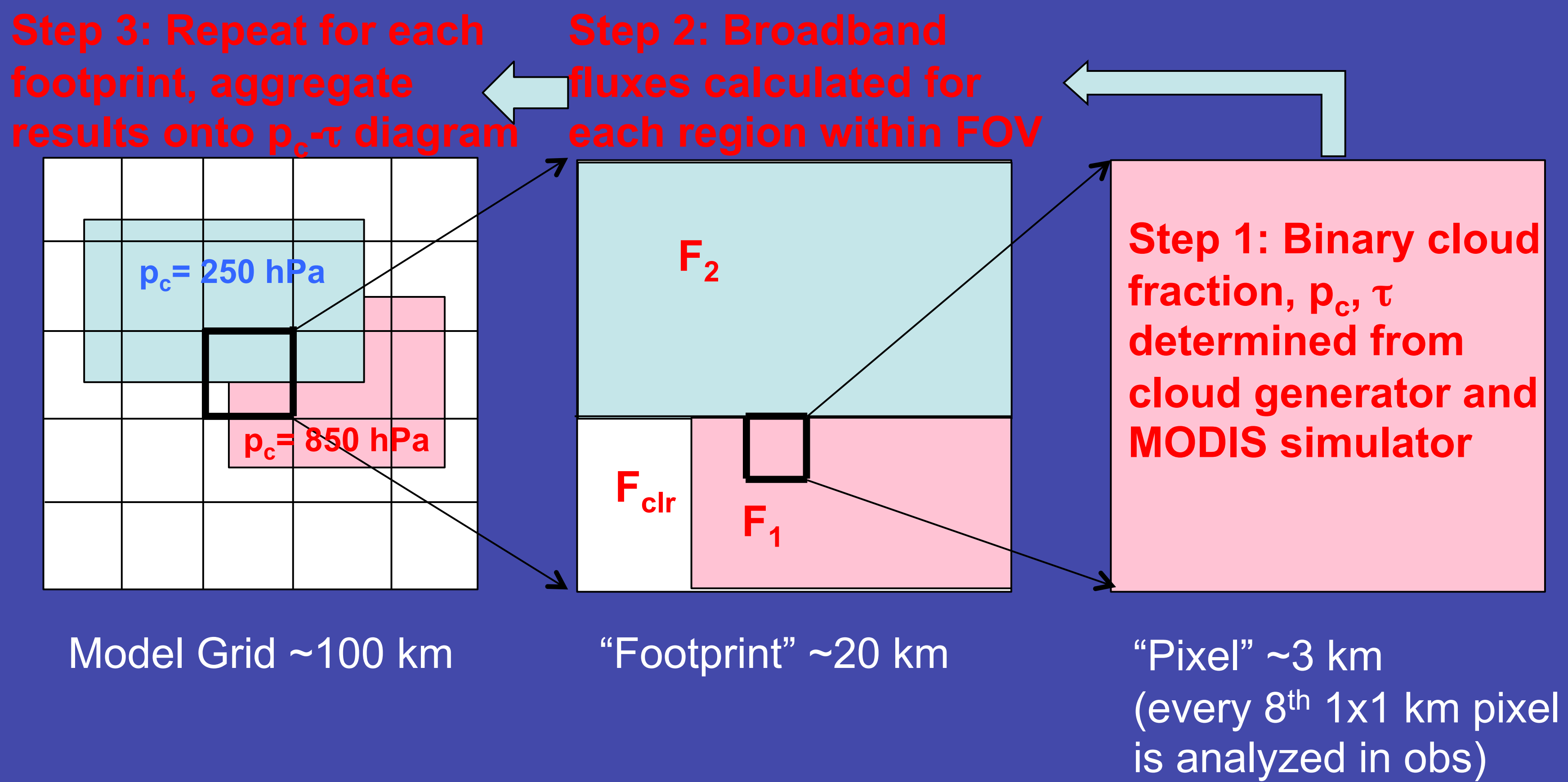

Note on RT calculations

- When assigning the flux to a CTP-τ bin, we use the retrieved CTP and τ from the MODIS simulator, but the flux is based on the actual cloud profile.
- For example, a column with a very thin cloud could be counted as “clear”, but its retrieved fluxes would take the cloud into account.

Benefits of this approach

- Cloud properties and fluxes/albedos are matched within 1.5 hours to the closest CERES overpass, which is important because of the large diurnal cycles in cloud fraction, τ, and p_c in many areas.
- Breaking out flux by cloud type can help isolate physical parameterizations that are problematic, and provide a test for new parameterizations.

What's in the CFMIP archive

- 7 participating modeling centers: CCCMA (Canada), CNRM (France), LASG (China), MRI (Japan), MPI-M (Germany), MOHC (UK), and NCAR.
- Only three of the models have 3-hourly profile data of air temperature, cloud amount, mass fraction of water/ice: CNRM, MRI, and MOHC. MRI doesn't seem to have stratiform cloud amount?
- Water vapor profiles are included at a six-hourly interval for all three models.
- Effective radii of water/ice, tau profiles and emissivity are included for MRI, MOHC only.
- 3-hourly land and sea ice skin temperature seems to only be included for CNRM, MRI only. Only MRI has 3-hourly SST, but all models have monthly mean skin temperature, which should be OK for SST.