Satellite cloud retrievals over the Northeast Pacific and research results relevant to CSET

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This presentation

- Brief overview and cloud retrievals validation
- GOES-15 cloud height variability and its potential use for entrainment rate calculations
- Regional patterns from satellite cloud microphysics products and aerosol transport model simulations

Dataset

- **Satellites**:
- Cloud effective radius (r_e), optical thickness (τ), **temperature**, and **fraction**
  - **CERES Edition 4 MODIS** retrievals (Terra and Aqua), 1km pixel resolution.
  - **SatCORPS Hourly GOES-15**: 4km pixel resolution (nadir-view)
  - Liquid water path **LWP=5/9$\cdot\rho_w\cdot r_e\cdot\tau$** (daytime only)
  - **Satellite-based cloud droplet number concentration (N_d), $N_d = K \bullet r_e^{-5/2} \bullet \tau^{-1/2}$ (daytime)**

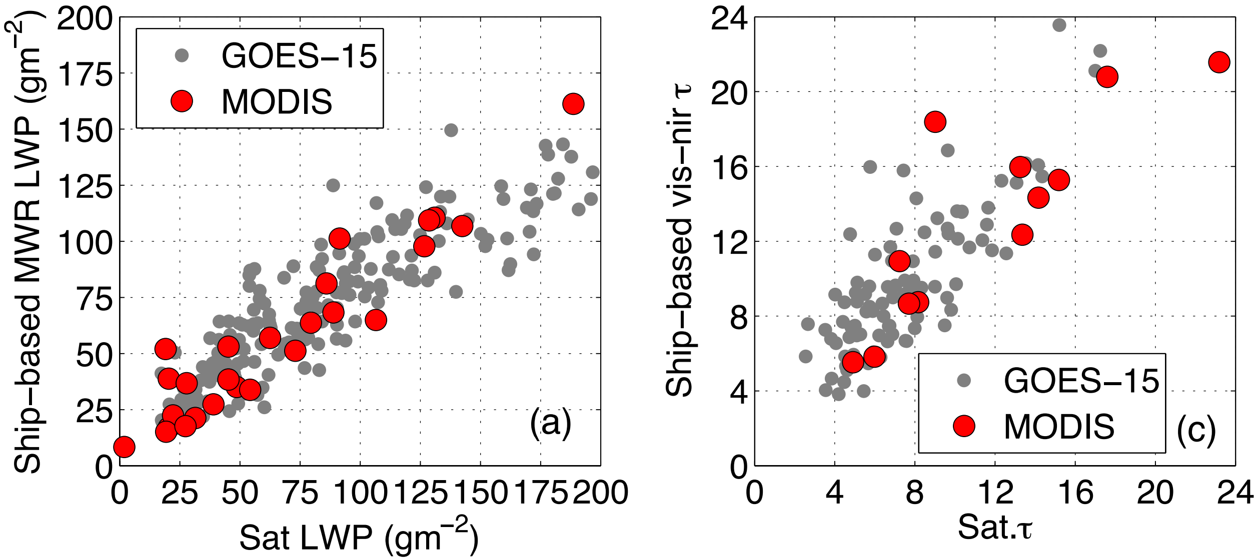
Dataset

- ***MAGIC data (validation purposes)***:
  - Clouds microphysics from a Cimel sun-photometer (Chiu et al. 2012 ACP): cloud optical depth (τ)
  - Three-channel microwave liquid water path (Cadeddu et al., 2013, AMT)
  - Cloud radar and radiosondes: cloud height and temperature
- ***Chemical transport model: GEOS-Chem v9-02***
  - NASA's MERRA reanalysis meteorological inputs
  - 2.5˚x2.0˚ spatial grid, 47 vertical levels (~14 below 2 km)
  - It transports 66 chemical tracers, including sulfate, ammonium, dust, carbon, sea salt, among others.
  - Simulation period: winter (2012-2013) and summer (2013)

Satellite validation: Cloud optical depth and liquid water path

- LWP:Ship-based 3-channel μwave radiometer
- Cloud optical depth (τ): sun-photometer (Chiu et al., 2012)

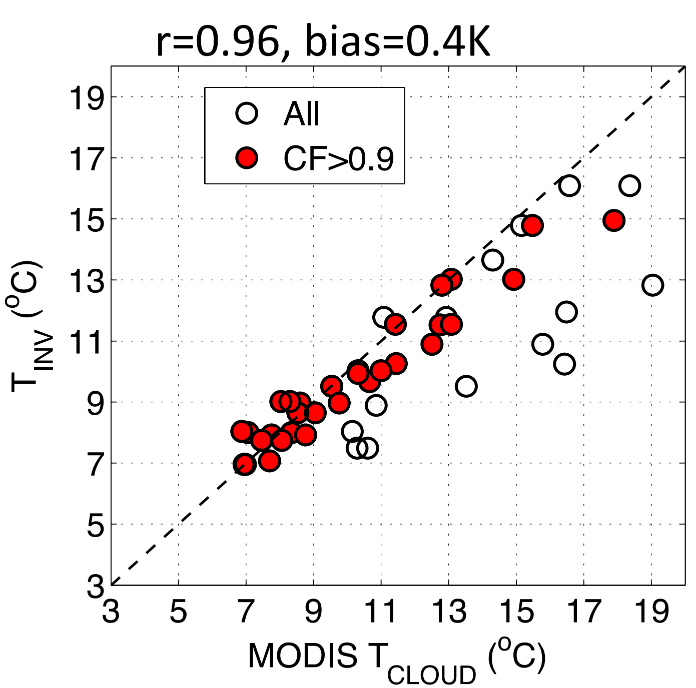
r=0.94, bias=9.1 g/m^2,rsme=18.9 g/m^2 r=0.85, bias=1.5, rsme= 3.21

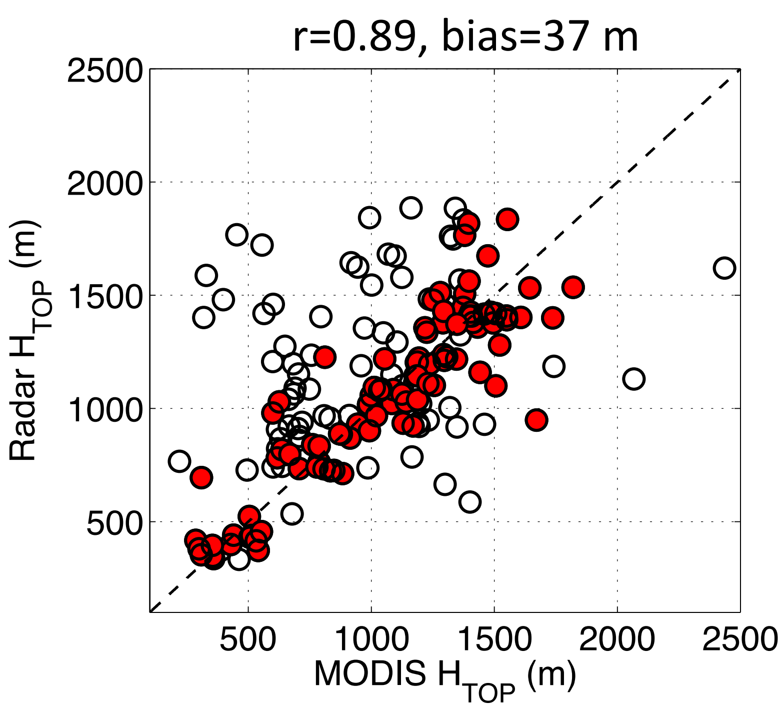


- Cloud effective radius? Comparison is uncertain, ground-based r_e is less robust than τ. <u>CSET measurements would be extremely valuable</u>.

Cloud temperature and height

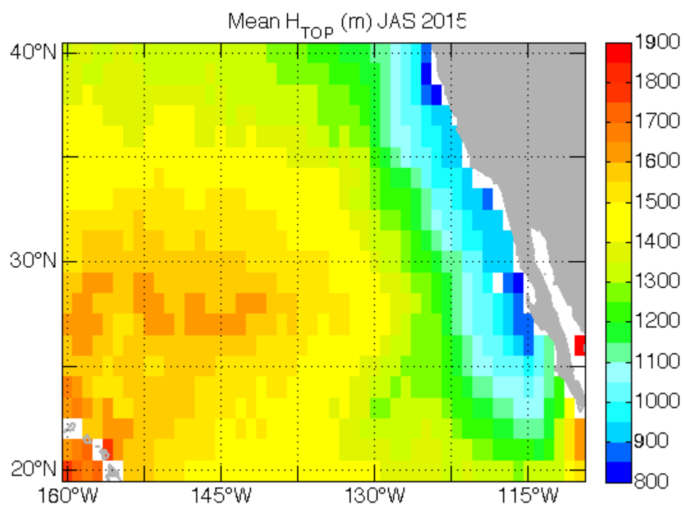
- MODIS cloud temperature vs inversion temperature (radiosonde)
- MODIS cloud height: linear fit from Painemal et al. 2013. It relates T_{top} – SST to cloud height.
- Ship-based cloud top height from a k-band radar (three months)



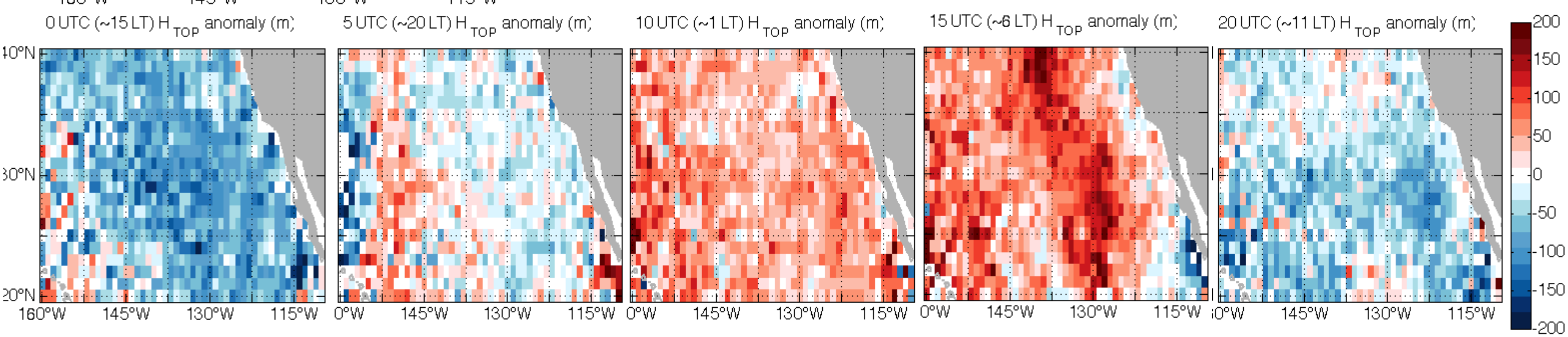


GOES-15 Cloud height

Cloud top height: mean and diurnal cycle (2015, CSET)



- GOES-15 mean height consistent with other climatologies



- Typical diurnal cycle in marine stratus, maximum (minimum) during the morning (afternoon)
- Less complex cycle than its SE Pacific counterpart (Painemal et al. 2013, JAS)

Entrainment rate calculation using GOES-15

- Budget equation for cloud top height (Z)

$$\frac{\partial Z}{\partial t} + V \cdot \nabla_H Z = w_e + w$$

Entrainment rate

Vertical velocity

advection

$$\frac{\partial < Z >}{\partial t} + < V \cdot \nabla_H Z > = < w_e > + < w >$$

$< X > = hourly\ composite$

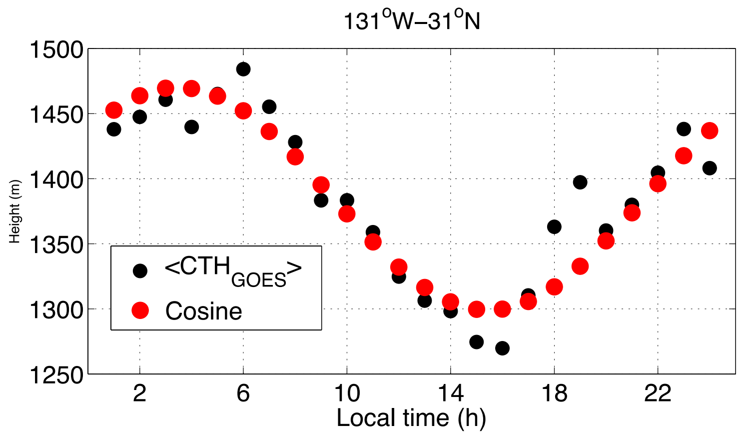
$$\boxed{< w_e > = \frac{\partial < Z >}{\partial t} + < V \cdot \nabla_H Z > - < w >}$$

ERA-Interim Reanalysis, 875 hPa

GOES-15 CTH

Computation of the term: $\frac{\partial < Z >}{\partial t}$

We fit a cosine function to the GOES-15 diurnal cycle.

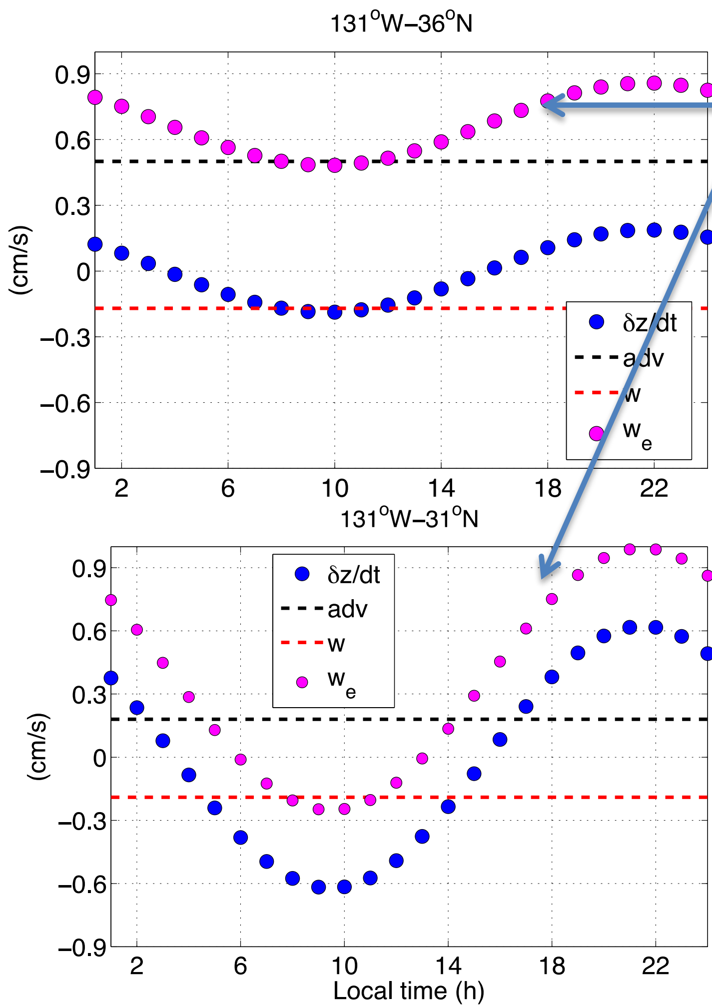


$$CTH_{fit} = A \cdot \cos\left(\frac{2\pi}{24h} \cdot (time - \phi)\right) + \overline{CTH}$$

$$\frac{\partial < Z >}{\partial t} = \frac{\partial CTH_{fit}}{\partial t} = -A \cdot \frac{2\pi}{24h} \cdot \sin\left(\frac{2\pi}{24h} \cdot (time - \phi)\right)$$

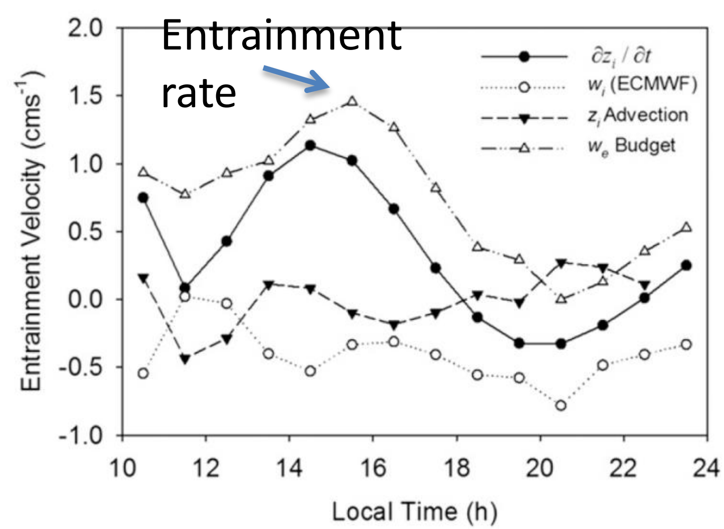
w_e diurnal cycle, a few examples

- Advective and vertical velocity terms are assumed constant with time and calculated as the average at 0, 6, 12, and 18 UTC



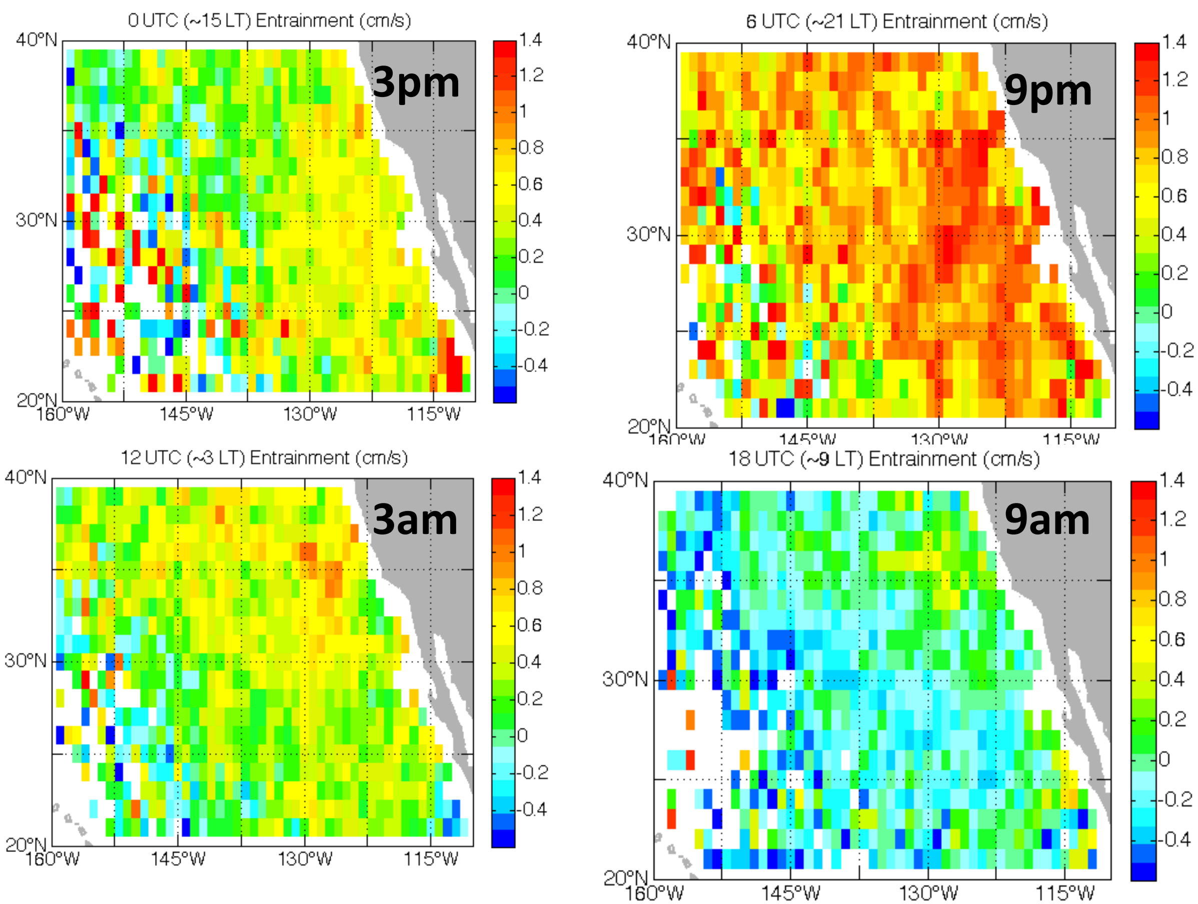
Entrainment rate

Albrecht et al (2015), continental



w_e diurnal cycle

- w_e is calculated at 00, 6, 12, and 18 UTC

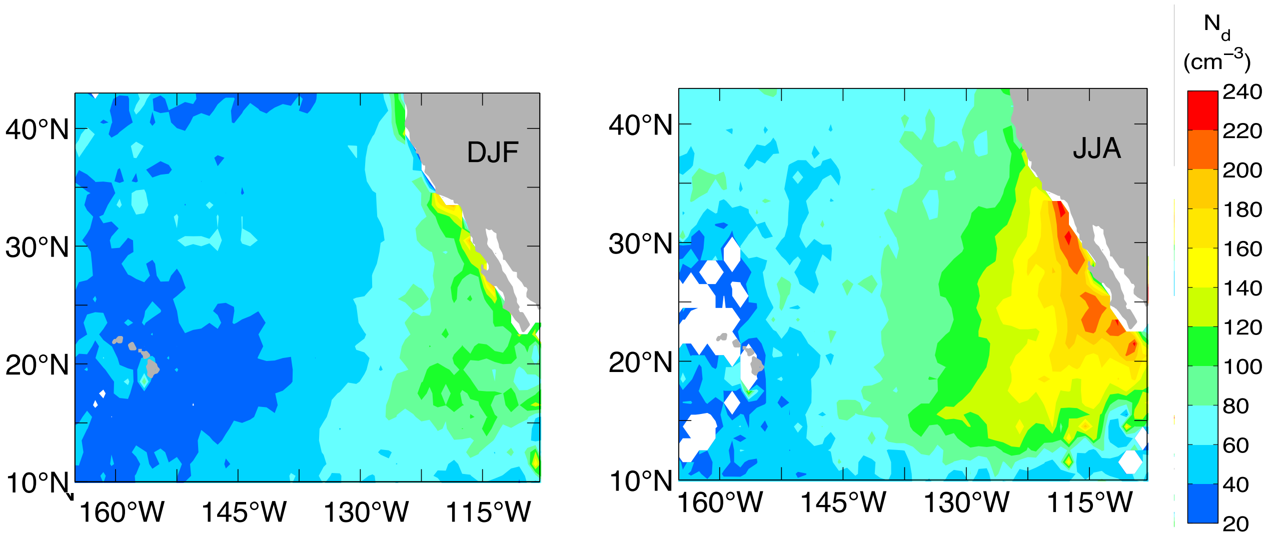


- CTH tendency dominates the diurnal cycle.
- Maximum entrainment around 9-10pm
- Minimum entrainment ~ 10am.

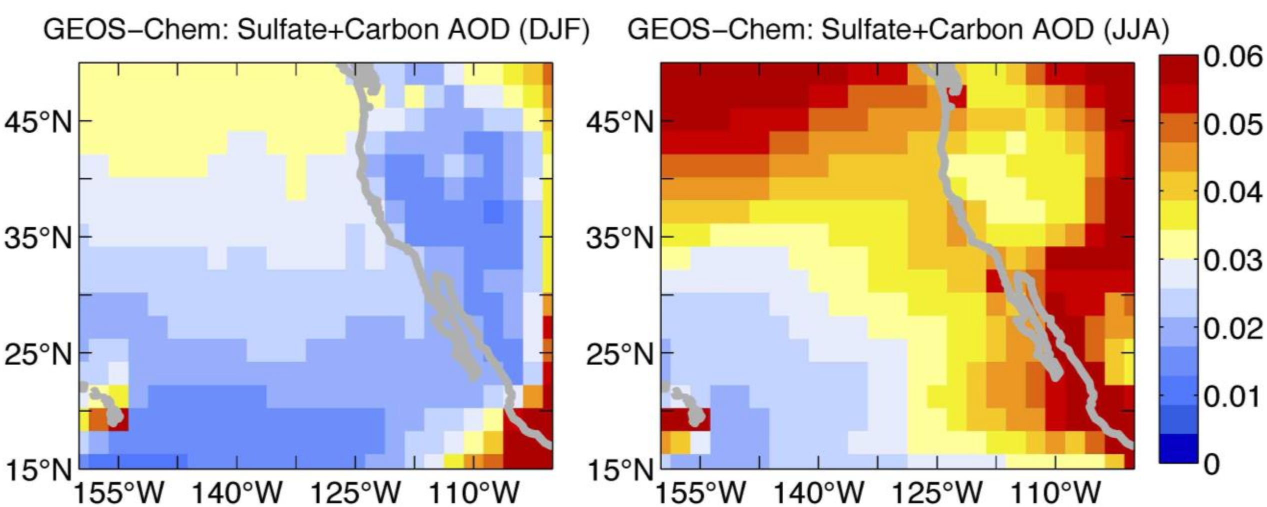
- Noisy fields might require further image processing/filtering.

Regional scale cloud microphysics and aerosol co-variability

MODIS N_d and simulated aerosols (without sea salt and dust). Seasonal progression



- ***CERES MODIS N_d***



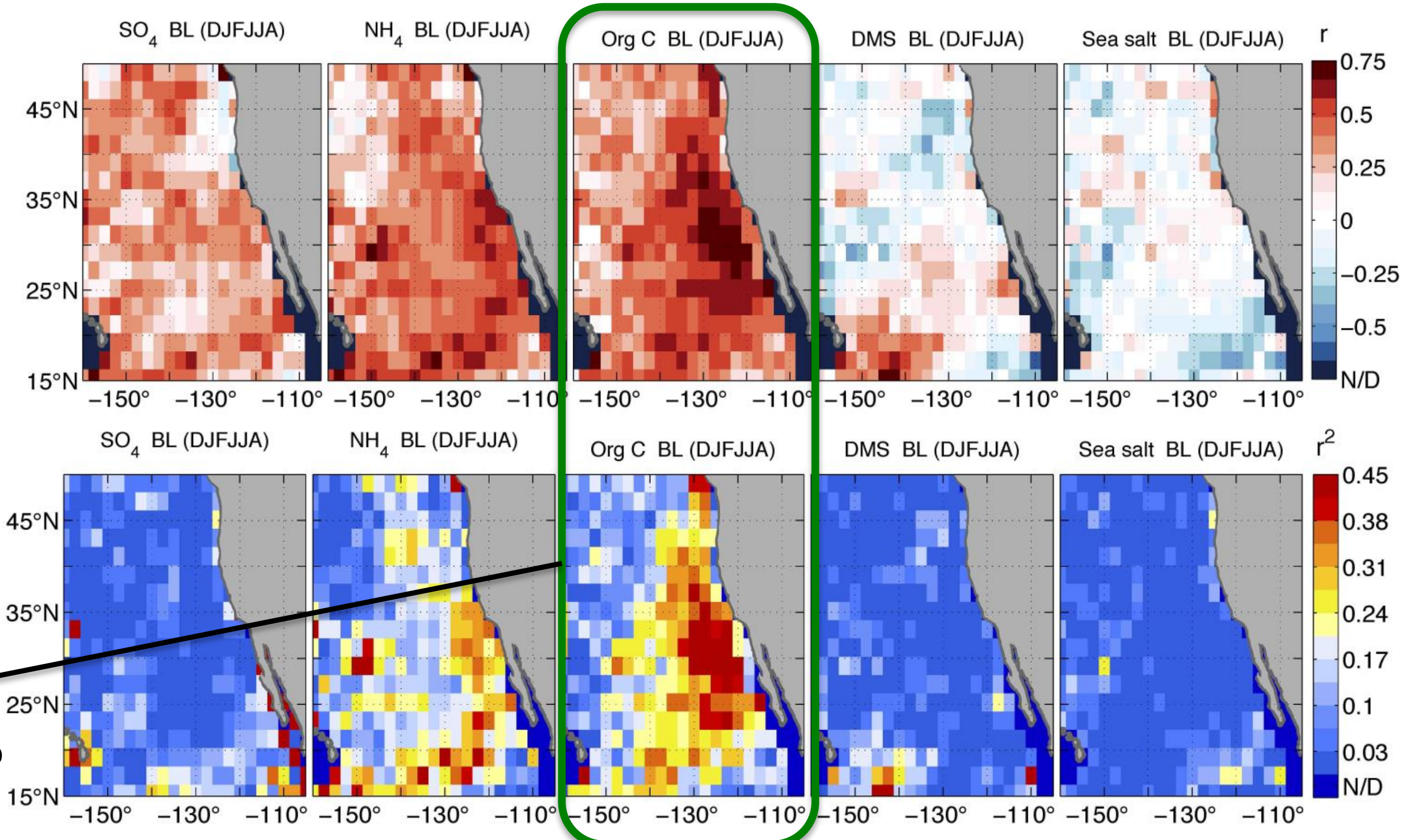
- ***GEOS-Chem simulations***

MODIS N_d and aerosol mass concentration correlation: Synoptic patterns

- Five chemical tracers correlated with daily MODIS *N_d:*
  - *Sulfate, Ammonium, organic carbon, dimethyl sulfide (DMS), sea salt.*
  - GEOS-Chem concentrations averaged below 1.5 km (~ boundary layer, BL)

Correlation coefficient

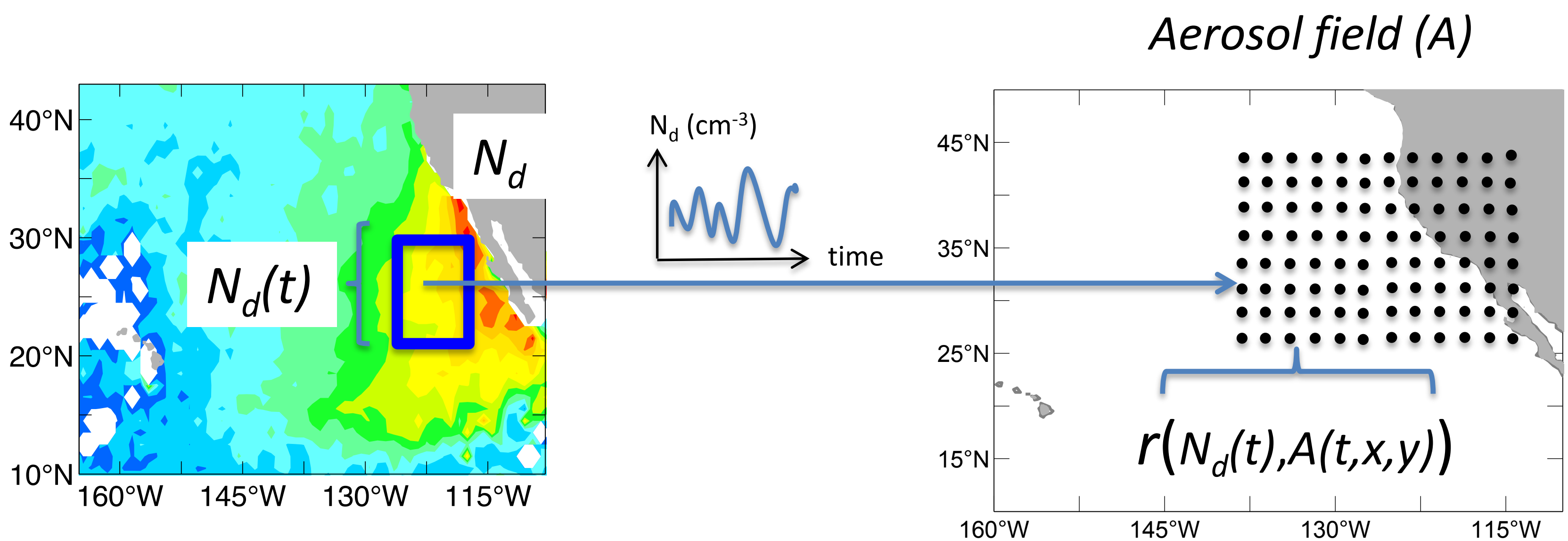
Coefficient of determination



Org. Carbon explains up to 45% of N_d variance

Where are the aerosols coming from?

- Aerosol candidates: organic carbon, SO_4
- One-point correlation analysis: N_d time series near California/Baja-California correlated with aerosol concentration fields.

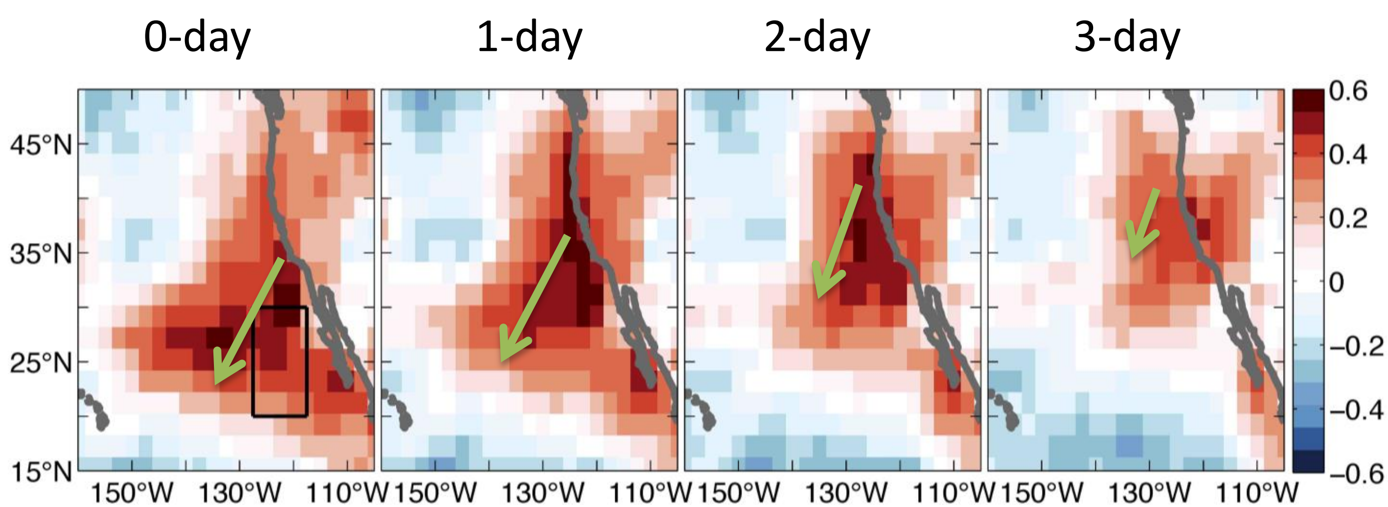


N_d and aerosols in the boundary layer (BL)

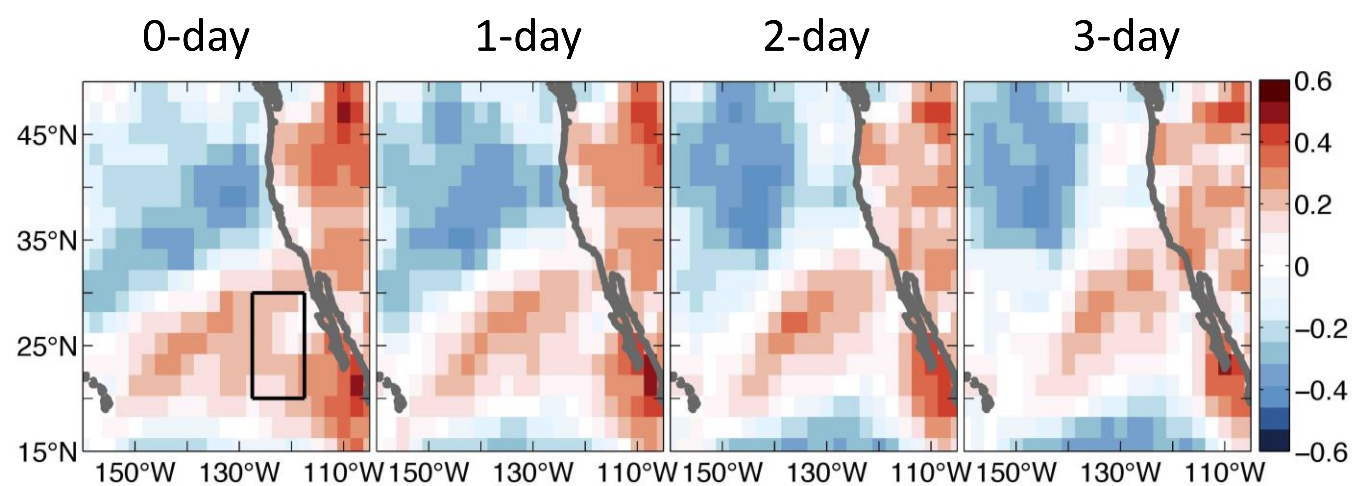
Aerosol field precedes N_d

- *Organic Carbon*

  - Southward propagating pattern from northern CA



- *Sulfate*

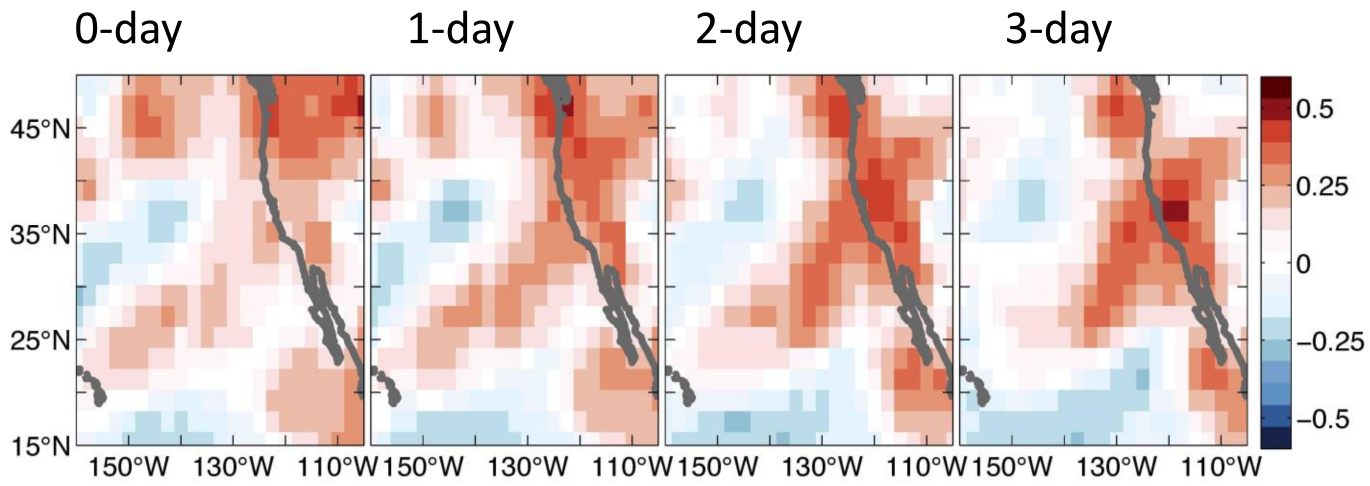


A few final points

- We are confident in the ability of our retrievals to reproduce realistic cloud properties.
- The link between satellite properties and precipitation warrants further analysis
- GOES-15 cloud microphysics can be used for Lagrangian studies
- Novel applications of GOES-15 includes the computation of entrainment rate. Is it useful?
- **Use our retrievals and help us validate them: If you like them, please spread the word.**

Extra: Aerosols in the free troposphere (2-2.5 km)

- *Organic Carbon*



- Absence of a clear pattern and weak correlations
- Free troposphere aerosols might be important over land