Seasonal Predictability of Cloud Droplet Number Concentration

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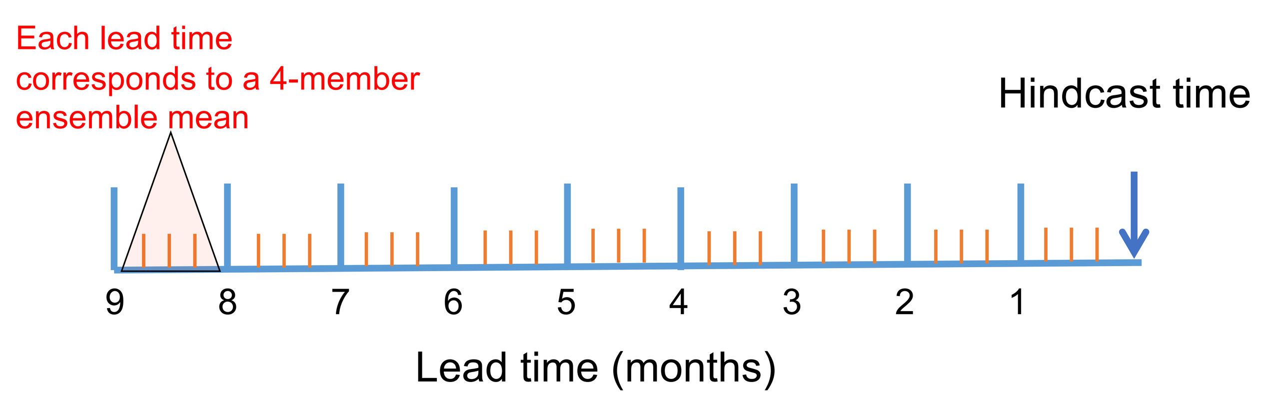
Motivation

Aerosol emissions modify the properties of clouds hence impacting climate. The aerosol indirect effect may have offset part of the global warming caused by anthropogenic greenhouse gas emissions during the industrial era. It however remains unclear whether the same effect is significant over time scales relevant for seasonal and subseasonal climate prediction. Answering such a question has been difficult since most weather prediction systems lack a proper representation of the aerosol evolution and transport and their interaction with clouds. Even in advanced systems it is not clear to what extent cloud microphysical properties are predictable over subseasonal to seasonal time scales.

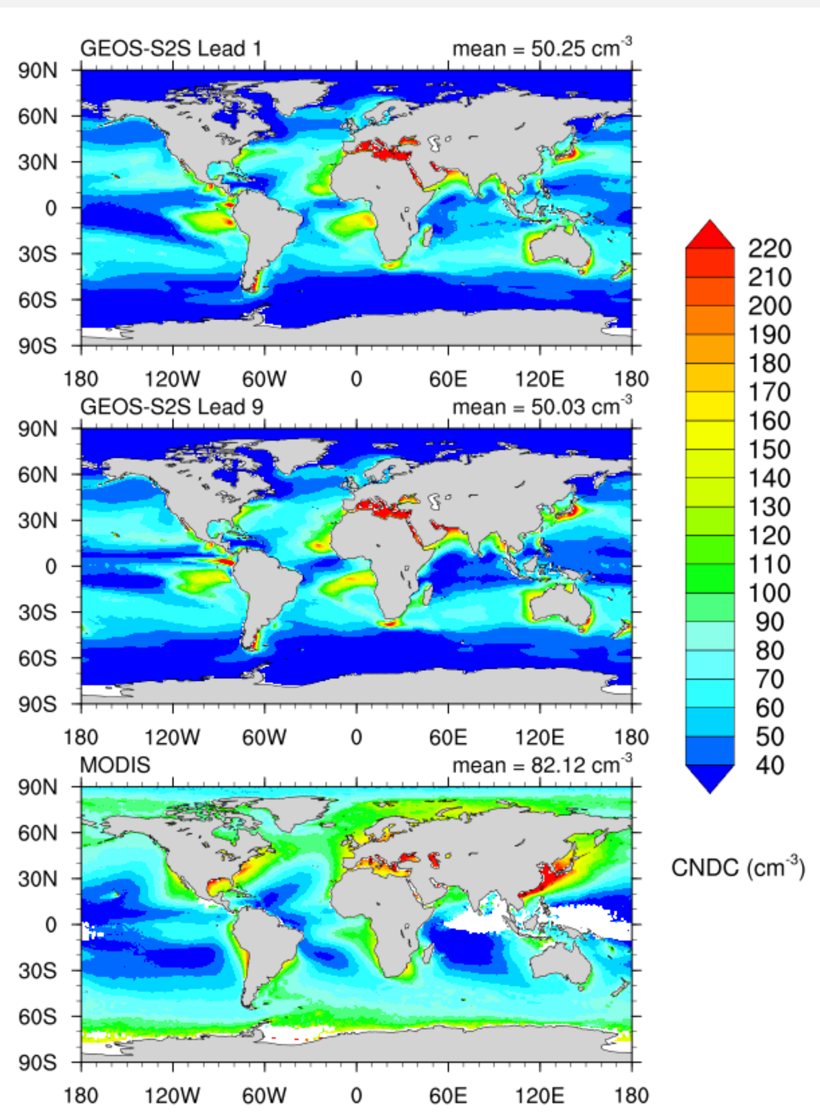
Hindcast Simulations

We use a set of 35 year (1980-2015), four ensemble member, 9 month lead hindcast (initialized using MERRA-2, Gelaro et al. 2016) simulations of the NASA GEOS seasonal prediction system (GEOS-S2S) to study the predictability of cloud droplet number concentration in warm stratocumulus clouds. GEOS-S2S is an atmosphere-ocean coupled system used operationally for seasonal prediction at the spatial resolution of 0.5 º. The latest version GEOS-S2S system implements interactive aerosol transport as well as a two-moment cloud microphysics scheme (Barahona et al. 2014) therefore it is suitable for studying the effect of aerosol-cloud interactions on climate.



Global Mean Cloud Droplet Number Concentration

Each lead time produces a 4-member ensemble mean of CDNC over the whole 35 year period. The comparison against MODIS-retrieved CDNC (Bennartz, et al. 2017) suggest a reasonable skill of the model in reproducing the global mean CDNC with notable exceptions in the Arctic and Antarctic regions.

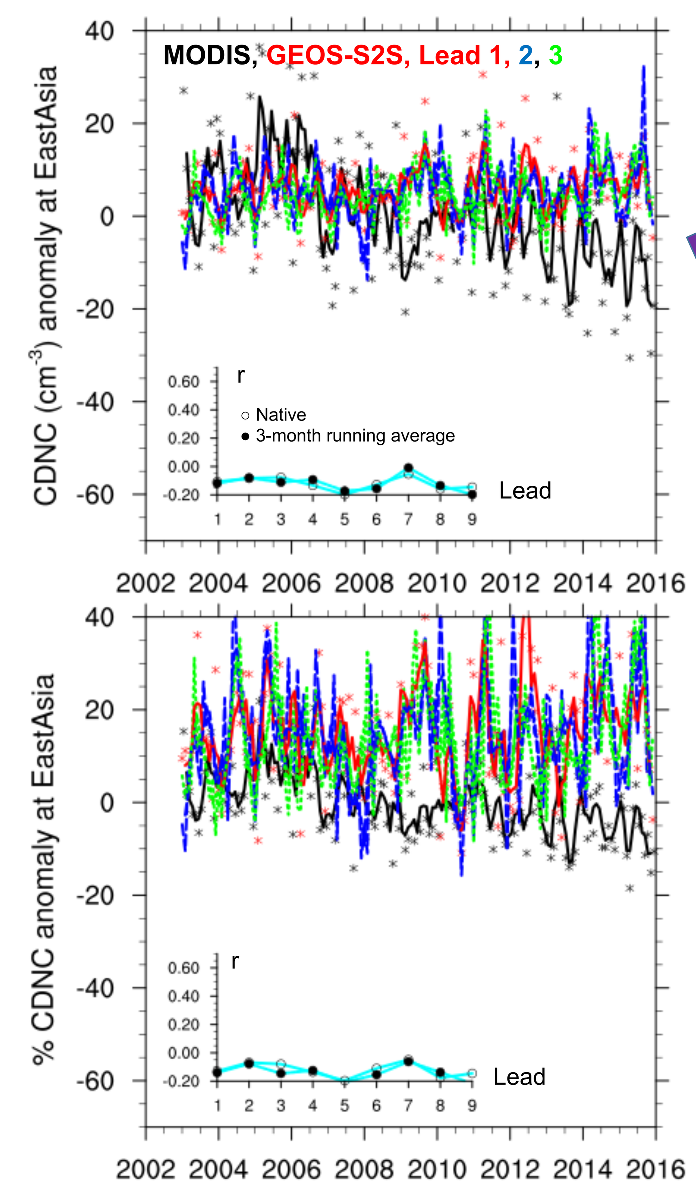


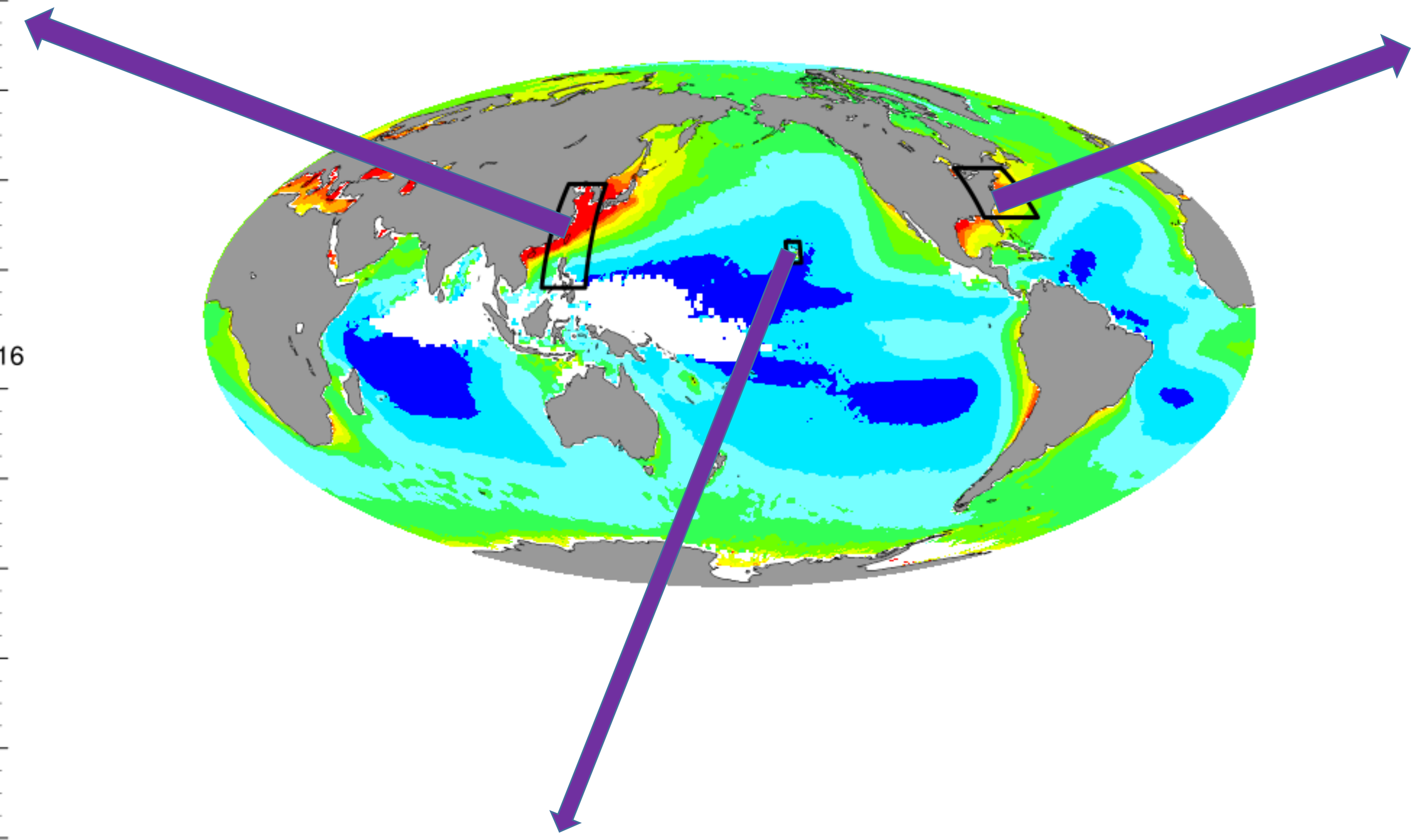
Global Mean CDNC changes very little between time leads 1 and 9.

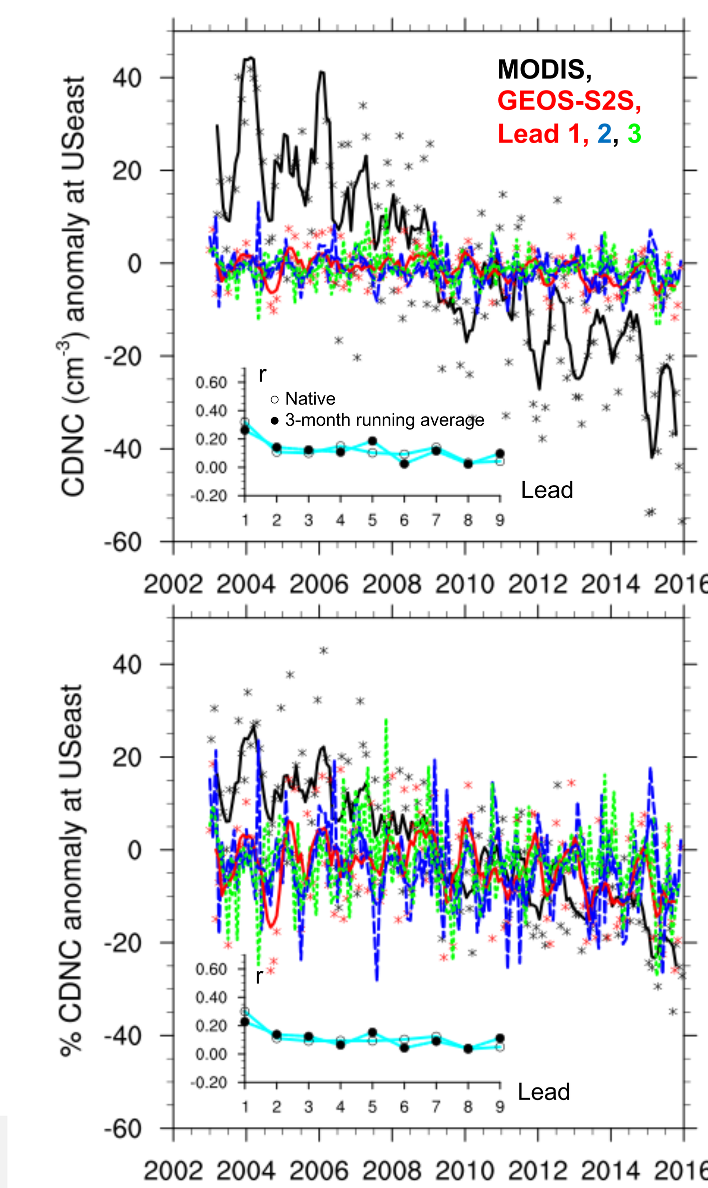
Sampling of the model may bias the satellite-model comparison since only adiabatic extended stratocumulus are included in the retrieval.

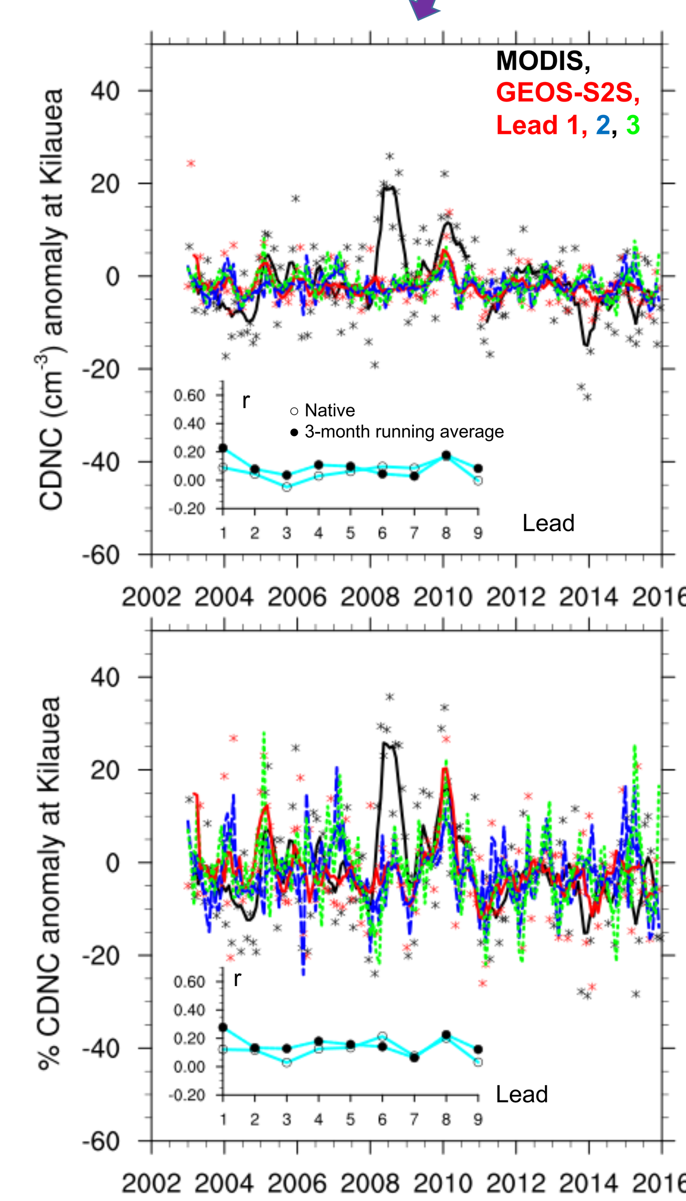
Regional Analysis

We use our set of hindcast simulations to study the predictability (measured in lead time) of CDNC in different regions where aerosol emissions may exert significant control on cloud properties.









East Asia

Aerosol emissions over the South China Sea has decreased over the past decade, and it is well reflected in the CDNC trend. For most of the period the model fails to capture such a trend and CDNC remains fairly constant over the whole period. As a result even at lead 1 the anomaly correlation with the retrieval is quite low.

Hawaii

Here the Kilauea crater is a continuous source of sulfate aerosols in an otherwise pristine region. This is typically reflected in modified cloud properties (Yuan et al. 2011).

At lead 1 the model is able to capture some of the variability in the region, although the correlation degrades rapidly beyond lead 2.

The effect of the 2008 degassing even is missing which is expected since short term sudden events typically have subseasonal time scales. The "aftermath" effect in 2009 however well captured by the model.

US East Coast

The US has seen a decrease in aerosol emissions during the last decade due to better emission standards and improved technology. CDNC has decreased as a result (McCoy et al. 2018). In absolute value, the model fails to capture such a decrease although displays some skill in the relative anomaly (%), particularly after 2008. The skill degrades rapidly beyond lead 1.

Conclusions and Outlook

In general GEOS-S2S was able to capture the main features of the global distribution of CDNC, independently of lead time.

Underprediction in CDNC was found in the Arctic and Antarctic regions and in the high-latitude regions. This could be ascribed to overactive freezing in GEOS-S2S which tends to thin mixed-phase clouds (Vergara-Temprano et al. 2017).

The analysis of the time series of CDNC in three aerosol-impacted regions of the world indicated no predictability in CDNC after lead time 1. This means that aerosol-cloud interactions may have little effect over seasonal scales although it could be also attributed to the onset of other confounding factors (i.e., meteorology) which could mask the aerosol effect on clouds. Discrepancy between the sampling of the model results and the retrieval assumptions, and model errors, may also affect the comparison.

At lead time 1 the model showed some skill in reproducing the MODIS anomaly, although it failed at reproducing long term CDNC tendencies in polluted regions. Since MERRA-2 is able to reproduce such trends (McCoy et al. 2018), the lack of skill may be the result of an initialization protocol that does not included assimilated aerosol.

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