POTENTIAL ROLES OF HIGH SPECTRAL RESOLUTION (HSR) SENSORS FOR CLIMATE CHANGE DETECTION

J.W. Snow, H.K. Burke, K.E. Farrar, Snow@ll.mit.edu; MIT Lincoln Laboratory, Lexington, MA

HSR-IR Sensors and Applications

High Spectral Resolution Satellite Infrared Sensors

HSR-IR Sensor(*)	Platform [year]	Orbit (LST)	Field-of-View dia (km), #/scan	Spectral Range (µm) (cm^{-1})	Spectral Resolution (cm^{-1})
IRIS(M)	Nimbus [1970]	12:00	100 1 nadir	6.3-25 (400-1600)	2.8
FSP(G)	Meteor-28 [1977]	…	… …	6.3-25 (400-1600)	5.0
HIS(M)	NASA ER-2 [1995+]	n/a	(aircraft)	5.7-25 (400-1750)	0.30
IMG(M)	ADEOS [10/96-8/97]	10:30	8x8sq 3	3.3-14 (714-3030)	0.28 to 0.10
AIRS(G)	EOS-Aqua [2003+]	13:30	13.5 90	3.7-15.4 (650-2700)	0.83
IASI(M)	METOP-I [2006]	13:30	12.0 30	3.6-15.5 (645-2760)	0.35 to 0.50
CrIS(M)	NPP [2006]	10:30	14.0 120	3.9-15.4 (650-2550)	1.44
HES(MG)	GOES-R [2012]	geo	~10.0 …	4.4-15.4 (650-2250)	0.625 to 1.25

*M – Michelson interferometer, G – Grating spectrometer.

Satellite Platform Properties Relevant to Climate

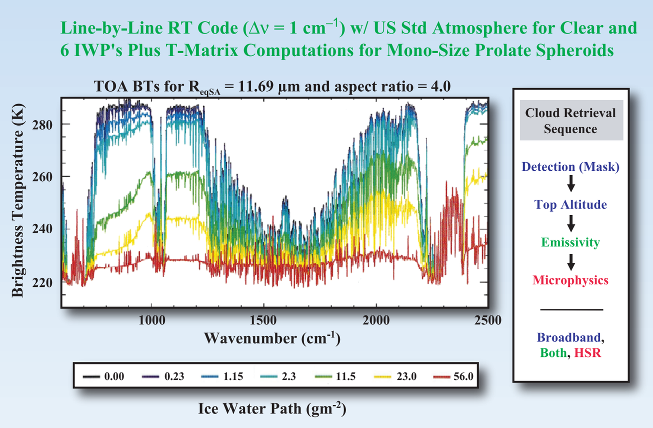
PROPERTY	GEO	POLAR	COMMENT
Prime area of coverage	Mid/low latitudes	All global latitudes	Dominant diurnal cycle at low lats
Cycle better monitored	Diurnal	Annual	Short time-constant feedbacks
Local solar time	Variable	Fixed	Change-signal in diurnal cycle
Viewing angle	Fixed	Variable	Angle correction error source
Revisit time	< 10 min	12 hours	Short time-constant feedbacks
Distance ($x10^3$ km)	35	~1	GEO signal strength compromised

POLAR monitors annual cycle and forcings
GEO monitors diurnal cycle and short-term feedbacks

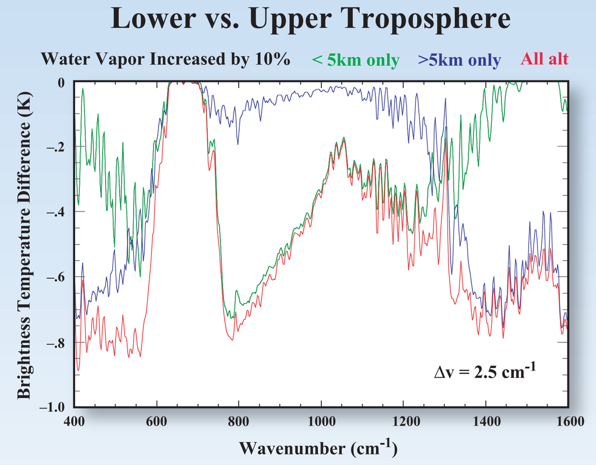
2nd Order Characteristics of Intrinsic Climate Variables

VARIABLE	CLIMATE CHANGE INFLUENCE	2nd ORDER EXAMPLES
Temperature	1) Small change in mean. 2) Larger signals in temporal differences and spatial gradients.	1) Diurnal range. 2) Vertical gradients in PBL and upper trop. 3) Horizontal advection.
Water Vapor Content	1) Most abundant green-house gas. 2) Major effect on spectral climate metrics.	1) Vertical change in spectral cooling rate. 2) Gradients above 500hPa 3) Changes below 500hPa.
Clouds	1) Time of day & duration. 2) Spatial extent and altitude. 3) Emissivity, CWP, and particle size.	1) Low-lat diurnal ranges. 2) Spectral emissivity change 3) Spectral PC analysis for CWP and particle size.

Cloud Microphysical Properties

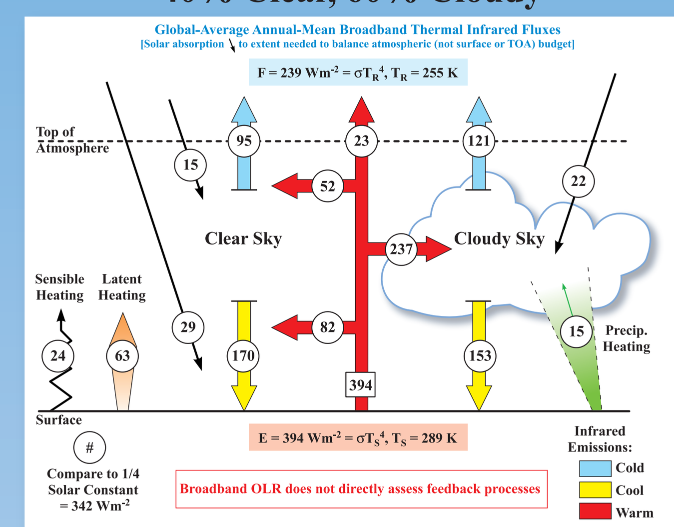


Sensitivity of Change in Water Vapor
Lower vs. Upper Troposphere

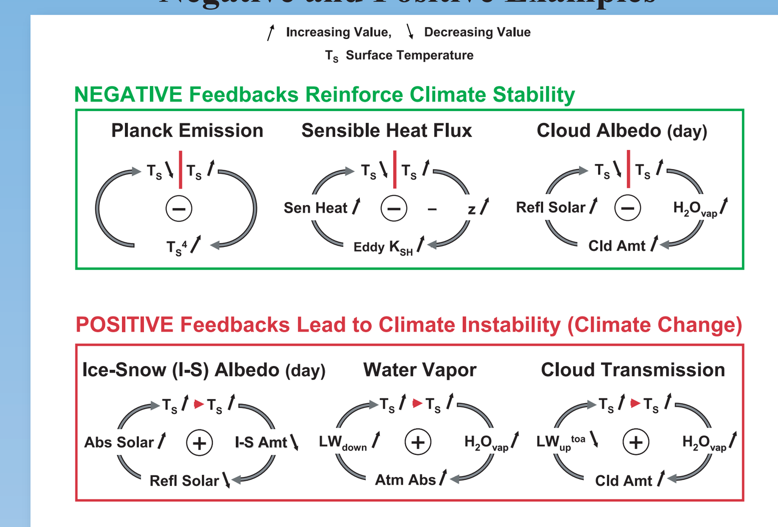


Climate Forcings and Feedbacks

Broadband Infrared Components of Energy Budget
40% Clear, 60% Cloudy



Feedback Processes
Negative and Positive Examples



Greenhouse Metrics

- Spectral Greenhouse Effect (W m^{-2}-cm^{-1}), net outgoing flux

  $$G_\nu = E_\nu - F_\nu$$

  - E_ν : Emission of the surface
  - F_ν : Outgoing longwave radiation (OLR)
  - G_ν : Absolute forcing of climate system

- Normalized Greenhouse Effect, spectral absorption

  $$g_\nu = (E_\nu - F_\nu) / E_\nu$$

- Spectral Cooling Rate (mK/day-cm^{-1})

  $$(\Delta T/\Delta t)_\nu = 8422 \ \Delta G_{\nu,(Z2-Z1)} / [P(Z_2) - P(Z_1)]$$

  P(Z) Atmospheric pressure at level Z (hPa)

Broadband Greenhouse Metrics for Three Cloud Conditions

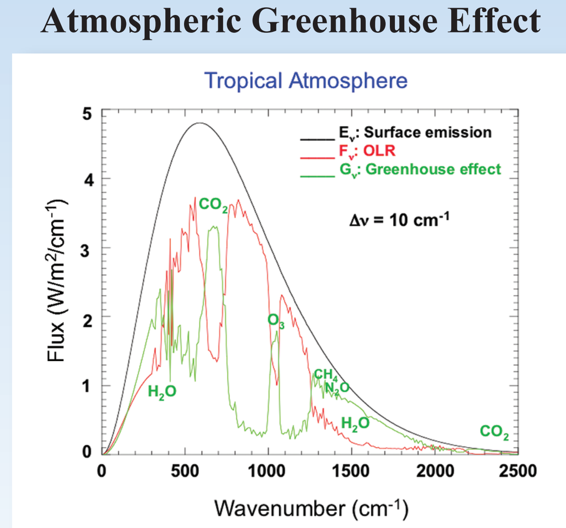
Blackbody temperature difference, $D = (T_S - T_R)$
Broadband absorbed flux, $G = E_S - F_{TOA}$
Normalized G, $g = (E_S - F_{TOA})/E_S = (1 - t_{IR})$

Earth	$S_o(Wm^{-2})$	α_P	T_R(K)*	T_S(K)	D(K)	G(Wm^{-2})	g#	Δ(%)@
Cloudy	1368	0.38	247	290	43	190	0.474	3.01
60% Cld	1368	0.30	255	289	34	155	0.394	4.15
Clear	1368	0.18	265	286	21	100	0.263	7.67

Greenhouse-effect increasing (cloudy condition) more difficult to detect than decreasing (clear condition).

Subscripts: S – surface, R – planetary BB temp, TOA – top-of-atmos, IR – thermal infrared
* $\sigma T_R^4 = (S_o/4)(1 - \alpha_P)$; S_o solar const, α_P planetary albedo
\# $g = (1 - t_{IR}) = (T_S^4 - T_R^4) / T_S^4$, infrared absorption fraction
@ Percent Difference in $g = (1 - t_{IR})$ for (T_S + 2K)

Spectral Variation of Total Atmospheric Greenhouse Effect



SUMMARY: Roles of Satellite HSR-IR for Climate Change Detection

Spectrally Resolved OLR Measurements

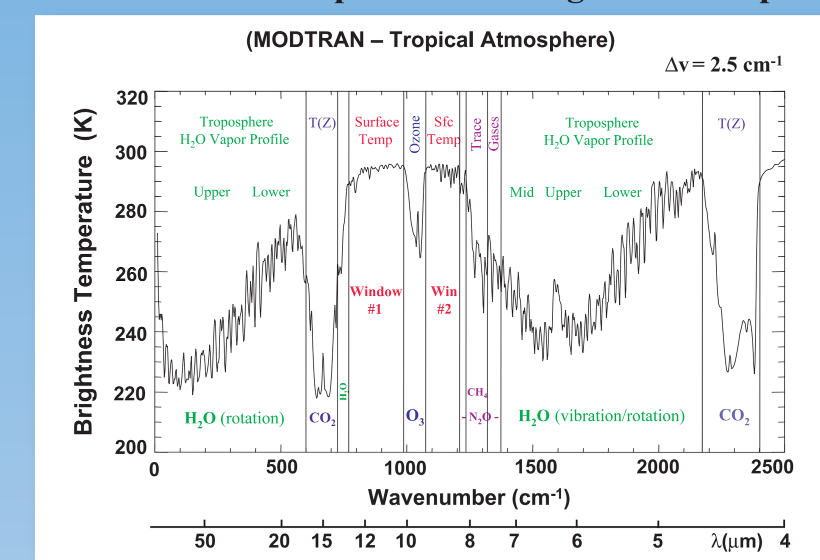
- Basic range 650 to 2500 cm^{-1} (4 to 15.5 µm)
- Far-IR desired 250 to 650 cm^{-1} (15.5 to 40 µm)

Allow Monitoring of Feedback Processes

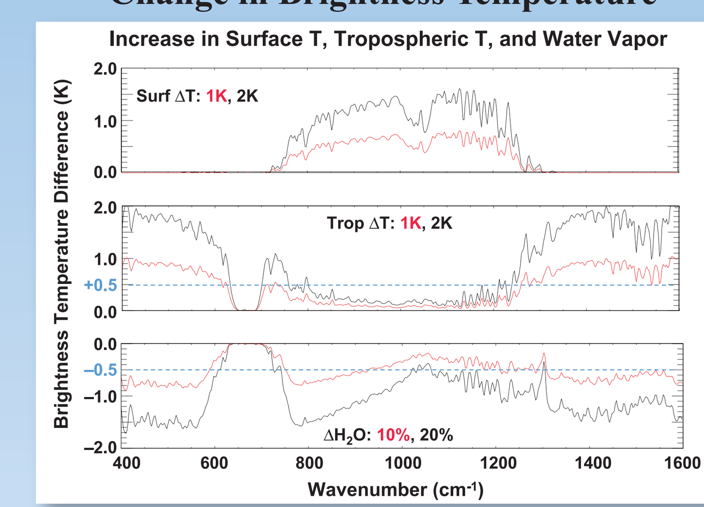
- Geostationary – diurnal, Polar – annual cycle
- Temperature differences and gradients, Greenhouse gas cooling rates, Cloud microphysics via spectral PC analyses
- Water vapor feedback using 720-780 cm^{-1}

Radiative Transfer Code Computations

HSR Thermal Infrared Spectrum of Brightness Temperature



Change in Brightness Temperature



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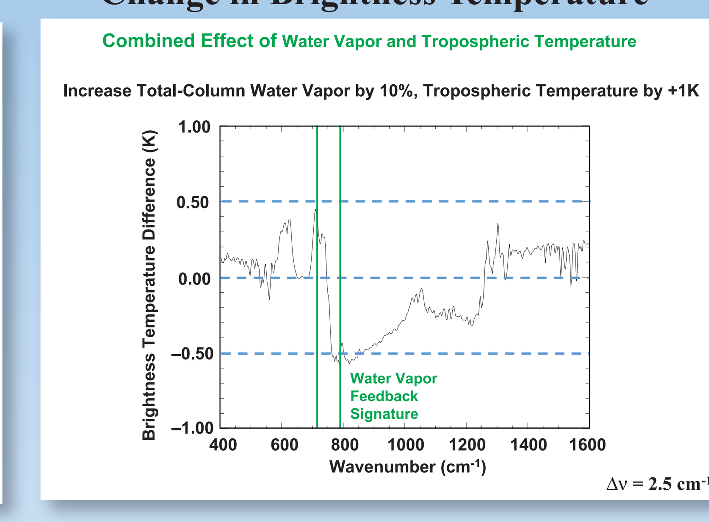
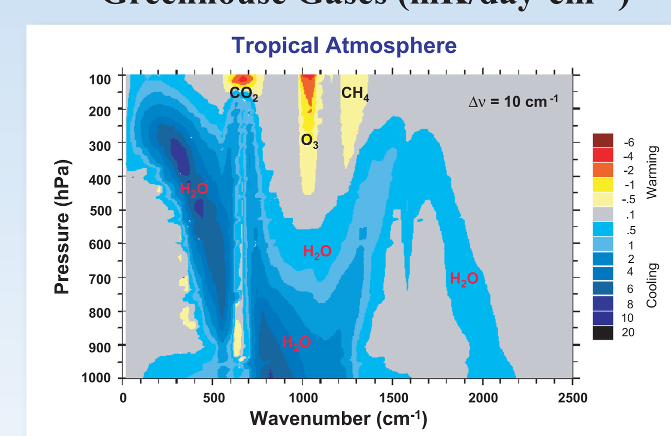


Spectral Cooling Rate Profiles for Greenhouse Gases (mK/day-cm^{-1})



Cooling Rate Change for +10% Water Vapor